NOTICE

All drawings located at the end of the document.

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FINAL

TECHNICAL MEMEORANDUM NO.1 TO FINAL PHASE I RFI/RI WORK PLAN

VADOSE ZONE INVESTIGATION

SOLAR EVAPORATION PONDS
(OPERABLE UNIT NO. 4)

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

ENVIRONMENTAL MANAGEMENT PROGRAM

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EXECUTIVE SUMMARY

A vadose zone investigation will be performed as part of the Phase I RCRA Facility Investigation/Remedial Investigation (RFI/RI) for the Solar Evaporation Ponds (Solar Ponds), Operable Unit 4 (OU4) at the Rocky Flats Plant (RFP). The vadose zone investigation is required to address the two preliminary objectives stated in the OU4 Phase I RFI/RI Work Plan (EG&G, 1992a):

- Characterize active vadose zone migration pathways; and
- Develop methodologies for closure and post-closure monitoring.

These objectives have been refined in this technical memorandum as follows:

- Characterize vadose zone soil contamination and active migration pathways within the vadose zone, and acquire an adequate understanding of the site to predict how the vadose zone will respond to changes in the system; and
- Develop a vadose zone data base to support preparation of the Baseline Risk Assessment (BRA), the Corrective Measures Study/Feasibility Study, and assist in development of monitoring approaches.

The vadose zone investigation has been designed primarily by using soil borings proposed in the OU4 Phase I RFI/RI Work Plan (EG&G, 1992a). Some additional borings will be required for installation of instrumentation at the double ring infiltrometer test site and Guelph permeameter locations.

Data available from previous work completed in the vicinity of OU4 have been collected and compiled and a preliminary review has been completed. Detailed review of this data will allow the initial identification of potential vadose zone pathways and construction of a preliminary three-dimensional geologic representation of the vadose zone.

In order to accomplish the above-stated objectives, the following activities are proposed as activities within this investigation;

- Physical and chemical analysis of vadose zone soil samples;
- Borehole permeability testing using the BAT® System to determine the range of hydraulic conductivities associated with the various geologic materials within the vadose zone;
- Collection of pore liquid from the vadose zone using lysimeters for analysis of chemical and radionuclide parameters;

- Double ring infiltrometer testing instrumented with tensiometers, time domain reflectrometry probes, frequency domain capacitance probes, and neutron probes to estimate ponded infiltration rates, soil-moisture relationships, field-saturated hydraulic conductivity, and integrated travel time in the unsaturated alluvium;
- Installation of transducers and data loggers in selected ground water monitoring wells to monitor the response of the water table to precipitation events and to determine whether responses occur as a result of secondary porosity; and
- Collection and analysis of soil gas for indications of contaminants.

Data generated from these activities will be used for:

- Estimation of the distribution of contaminants, by phase, in the vadose zone;
- Development of a three-dimensional geologic representation of the vadose zone using a Geographic Information System;
- Preparation of a water balance to estimate past, present, and future vadose zone fluxes;
- Data generation to predict the rate of leaching of contaminants out of the vadose zone;
- Evaluation of the applicability of simple numerical models of vadose zone transport to provide a predictive capability for use in evaluating remedial alternatives; and
- Selection of suitable site-specific monitoring techniques for use in a long-term monitoring program.

The final products of the vadose zone characterization will consist of refinement of the OU4 conceptual model describing the types of contamination, pathways, and a strategy for future monitoring activities. The vadose zone characterization, except for any ongoing monitoring results, will be integrated into the Solar Ponds Phase I RFI/RI Report.

1.0 INTRODUCTION

The Solar Evaporation Ponds (Solar Ponds) are located in the northeast portion of the Rocky Flats Plant (RFP) site on the northeast side of the Protected Area (PA). Operable Unit Number 4 (OU4) encompasses the Solar Ponds and other features considered pertinent to the investigation of the Solar Ponds. It includes the Solar Ponds which lie within Individual Hazardous Substance Site (IHSS) 101, three historic earthen ponds, the Interceptor Trench System (ITS), and areas in the immediate vicinity of the Solar Ponds. A 1991 aerial photograph of the Solar Ponds area appears in Figure 1-1. A map of the OU4 area is presented in Figure 1-2. The existing Solar Ponds consist of five surface impoundments referred to as Ponds 207A, 207B-North, 207B-Center, 207B-South, and 207C.

The vadose zone is defined for this project to include all strata from topsoil to the first occurrence of unconfined saturated conditions. The vadose zone will include surficial materials consisting of Rocky Flats Alluvium, colluvium, and valley fill alluvium, disturbed material, and artificial fill materials. The vadose zone may also include weathered bedrock lithologies of the Arapahoe Formation. Both saturated and unsaturated conditions are found in the surficial materials and in the weathered bedrock lithologies. Borings will be terminated at a depth of five feet below the surface of the weathered bedrock.

Sitewide geological studies and work recently completed at Operable Unit 1 (OU1) have identified two distinct hydrostratigraphic units (HSUs) of concern at RFP. The term HSU is used to denote a potential ground water bearing unit and is somewhat analogous to the term "aquifer". Use of the word "aquifer" connotes an ability of a water-bearing unit to produce water at exploitable rates.

The two HSUs at the site exhibit different hydrogeologic characteristics. The upper HSU is an unconfined unit and consists of Quaternary and recent unconsolidated surficial material including Rocky Flats Alluvium, valley fill alluvium, colluvium, disturbed material, and artificial fill materials. The upper HSU also includes the underlying weathered bedrock. Hydraulic conductivities for the surficial materials have been intensely studied and range

Hydraulic conductivities for the surficial materials have been intensely studied and range from 4×10^{-4} to 9×10^{-7} centimeters per second (cm/s). The unweathered bedrock hydraulic conductivities range from 2×10^{-6} to 2×10^{-7}. The lower HSU is a confined unit and consists of unweathered consolidated Cretaceous bedrock claystones, silty claystones, and silty sandstones. Both the Arapahoe and the Laramie Formations comprise the lower HSU. Hydraulic conductivities of the unweathered lower HSU range from 9×10^{-7} to 1×10^{-8} cm/s and 2×10^{-6} to 2×10^{-7} cm/s for the weathered bedrock. The deeper, regional ground water aquifer consists of confined hydrostratigraphic units of the Laramie and Fox Hills Formations which consist of unweathered claystone and sandstone. Available data indicate that contamination is not present in the unweathered bedrock lithologies.

The vadose zone, as defined for this investigation, lies exclusively within the upper HSU. The applicability of these defined HSUs to the conceptual model of the OU4 study area will be determined during the overall Phase I RFI/RI investigation.

Spatial and temporal characterization of the hydrology and geochemistry of the vadose zone is critical for developing an understanding of the flux of water and contaminants through the vadose zone to the underlying ground water at the Solar Ponds. The process of water movement through the soil zone into the underlying intermediate vadose zone is complex. Elements contributing to the complexity of flow include precipitation variability, variations in the state of water saturation, and spatial variations in the physical and hydraulic properties of the vadose zone.

1.1 PROJECT AREA

The Solar Ponds were constructed primarily to store and treat by evaporation low-level radioactive process wastes containing high nitrate concentrations and neutralized acidic wastes containing aluminum hydroxide. During their use, these ponds received additional wastes such as sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfate, hydrochloric acid, nitric acid, hexavalent chromium, and cyanide solutions (Rockwell International, 1988). Solvents and other organics have not been routinely discharged to the ponds because of the potential of causing algal growth which would diminish solar evaporation. However, low concentrations of organohalogen solvents may have been present as minor constituents in other aqueous wastes derived from drains in the 700 series buildings.

Three earthen ponds existed prior to the current ponds and were in use from 1953 to 1960. The Original Pond (Pond 2), was a clay-lined impoundment constructed in 1953. Pond 2-Auxiliary was originally an unlined pond constructed in 1955 at the southeast corner of Pond 2 to be used for excess capacity. It was later redesigned with a compacted clay liner. A third earthen pond, located east of Pond 2 and north of Pond 2-Auxiliary, was constructed in 1959. All three of the earthen ponds were removed from use in late 1960.

Pond 207A was the first of the existing ponds to be placed in service. It was completed in August 1956, with a liner of asphalt planking. The asphalt planking was later removed during pond redesign activities, and was replaced with a three-inch thickness of asphaltic concrete. In the fall of 1988, a rubberized crack-sealing material was placed on the side slopes of Pond 207A. Ponds 207B-North, 207B-Center, and 207B-South were placed in service in June 1960. Pond 207C was constructed in 1970 to provide additional storage capacity and to allow the transfer and storage of liquids from the other ponds in order to perform pond repair work. It has an asphaltic concrete liner and is equipped with a leak detection system.

The routine placement of process waste material into the Solar Ponds ceased in 1986 because of changes in RFP waste treatment operations. Presently, Pond 207A has been cleaned out, and periodically contains small volumes of precipitation. The 207B ponds have most recently been used for storage and treatment of intercepted water collected by the ITS, but the liquids in these ponds are currently being evaporated. Liquid from the Pond 207A cleanout operations was pumped into the Pond 207B series ponds.

The Solar Ponds were first identified as a RCRA regulated unit in the early 1980s. An interim status closure plan was prepared for the Solar Ponds in 1986 in accordance with a Compliance Agreement between the U.S. Department of Energy (DOE), the Colorado

Department of Health (CDH), and the U.S. Environmental Protection Agency (EPA). The closure plan was revised in 1987 and again in 1988. DOE and the State of Colorado entered into an Agreement in Principle (AIP) which specified that cleanup of the Solar Ponds would be expedited in order to address the contribution of the Solar Ponds to the release of potentially harmful contaminants into the ground water and soil. The January 1991 Interagency Agreement (IAG) negotiated among DOE, EPA, and the State of Colorado established the Scope of Work and schedule for the Phase I RFI/RI at OU4. Phase I requires the characterization of potential sources and soils occurring on and beneath OU4.

Water is currently being removed from the Solar Ponds as part of an Interim Measure/Interim Remedial Action (IM/IRA). Sludge removal and solidification is being done as part of the closure plan. Halliburton/NUS has been contracted to remove the liquids and sludge, and to immobilize contaminants in the sludge through fixation. The sludge is mixed with Portland cement and formed into blocks, a process referred to as "pondcreting". The schedules for the Phase I RFI/RI at OU4 and IM/IRA activities at the Solar Ponds overlap significantly. Coordination of OU4 Phase I RFI/RI activities with the pond cleanout program is mandatory to complete RFI/RI activities in a timely manner.

1.2 OBJECTIVES

Vadose zone monitoring techniques can be used to characterize and identify the contaminant source, identify the extent of vadose zone contamination, and identify active subsurface migration pathways which provide potential routes for subsequent ground water contamination. In addition, knowledge of the physical properties of the vadose zone is necessary for the subsequent risk analysis, feasibility study, and evaluation of closure options.

The OU4 Phase I RFI/RI Work Plan (EG&G, 1992a) presents preliminary objectives for vadose zone investigations including:

- Characterize active vadose zone migration pathways; and
- Develop methodologies for closure and post-closure monitoring.

In order to accomplish these objectives, the following activities were proposed in the Phase I RFI/RI Work Plan:

- Characterize infiltration, vadose zone storage, and water table recharge in the Solar Ponds area;
- Determine vadose zone storage and downward transmission of infiltration in response to precipitation events;
- Correlate potential perched water horizons between the Solar Evaporation Ponds area and downslope seeps;
- Evaluate sample collection techniques for vadose zone pore water; and
- Investigate vadose zone water quality.

The Work Plan objectives and activities were evaluated during preparation of this technical memorandum, and have been refined as follows:

- Characterize vadose zone soil contamination and migration pathways within the vadose zone, and acquire an adequate understanding of the site to predict how the vadose zone will respond to changes in the system; and
- Develop a vadose zone data base to support preparation of the Baseline Risk Assessment (BRA), the Corrective Measures Study/Feasibility Study, and assist in development of monitoring approaches.

Specific activities that have been identified to accomplish these objectives include:

- Physical and chemical analysis of vadose zone soil samples;
- Borehole permeability testing using the BAT® System to determine the range of hydraulic conductivities associated with the various geologic materials within the vadose zone at OU4, and comparison to other data collected within the RFP;
- Collection of pore liquid from the vadose zone for analysis of chemical and radionuclide parameters;

- Double ring infiltrometer testing instrumented with tensiometers, time domain reflectrometry probes, frequency domain capacitance probes, and neutron probes to estimate ponded infiltration rates, in-situ soil-moisture relationships, field-saturated hydraulic conductivity, and integrated travel time in the unsaturated alluvium;

- Installation of transducers and data loggers in selected ground water monitoring wells to monitor the response of the water table to precipitation events and to determine whether responses occur as a result of secondary porosity; and

- Collection and analysis of soil gas for indications of contaminants.

Data generated from these activities will be used for:

- Estimation of the distribution of contaminants, by phase, in the vadose zone;

- Development of a three-dimensional geologic representation of the vadose zone using a Geographic Information System;

- Preparation of a water balance to estimate past, present, and future vadose zone fluxes;

- Data generation to predict the rate of leaching of contaminants out of the vadose zone;

- Evaluation of the applicability of simple numerical models of vadose zone transport to provide a predictive capability for use in evaluating remedial alternatives; and

- Selection of suitable site-specific monitoring techniques for use in a long-term monitoring program.

This Technical Memorandum to the OU4 Phase I RFI/RI Work Plan has been developed to investigate the transmission of fluids and gases through the vadose zone and to establish the composition of these mobile phases.

1.3 RELATED INVESTIGATIONS

Related investigations include previous Solar Pond investigations and other vadose zone investigations presently underway or proposed at RFP. These investigations are discussed in the following sections.

1.3.1 Previous Solar Pond Investigations

The Solar Ponds area has been the subject of many studies to determine various physical and chemical characteristics of the area. Investigative activities conducted at OU4 and other pertinent studies are summarized in Table 1.1 and more details are included in Appendix A. The data from these studies are being assembled and evaluated in detail. The following points summarize current knowledge of the subsurface system in the vicinity of the Solar Ponds, and are being used to guide the placement of boreholes and determine what data must be generated at each specific location.

- The Solar Ponds are in an interim status Assessment Monitoring Program for ground water quality (EG&G, 1992b). The Assessment Monitoring program indicates that ground water contamination, consisting of elevated nitrate and radionuclides, has already been verified.

- Similar contamination is present in saturated surficial materials and saturated weathered bedrock lithologies in the Solar Pond area (EG&G, 1992b). Lower unweathered units have relatively low hydraulic conductivities (EG&G, 1992b), and existing wells demonstrate the absence of water quality impacts within these strata.

- The uppermost unconfined HSU consists of saturated and unsaturated surficial materials, (Rocky Flats Alluvium, colluvium, valley fill alluvium, disturbed materials, and artificial fill) as well as saturated and unsaturated weathered bedrock lithologies (EG&G, 1992b).

- The lower confined HSU in the Arapahoe and Laramie Formations consisting primarily of unweathered siltstone and claystone with minor sandstone is not considered part of the upper HSU. Transmissive weathered sandstones in contact with the uppermost unconfined HSU appear isolated and discontinuous within the Solar Ponds area. These isolated sandstones are unlikely to provide effective flow conduits into the lower HSU due to the low vertical permeabilities of unweathered claystones.

- The vadose zone materials are chemically and physically heterogeneous and where possible should be distinguished by the following categories to adequately characterize the site:

  - surficial materials directly under the Solar Ponds;

  - surficial materials near the Solar Ponds that have not slumped consisting of Rocky Flats Alluvium, colluvium, and valley fill alluvium;

  - surficial materials near the Solar Ponds that have slumped;

  - artificial fill materials near the Solar Ponds;

  - cemented caliche zones within the surficial materials; and

  - weathered bedrock lithologies in the project area which may consist of weathered sandstone, weathered claystone, and weathered silty claystone.

- Vertical and lateral variabilities are of particular concern due to the extensive disturbance and natural topographic relief in the area.

- Significant information is available regarding subsurface geology in the Solar Pond area. This information has been generated in the Solar Pond area and in other nearby Operable Units as part of an on-going Sitewide Geologic Characterization Project.

- The most recent annual RCRA ground water monitoring report, March 1, 1992 (EG&G, 1992b), included potentiometric surface maps in surficial materials and in weathered bedrock lithologies. These maps indicate a large unsaturated area present in both surficial materials and weathered bedrock lithologies beginning immediately north of the 207C Solar Pond and trending to the east-northeast. Although the annual RCRA ground water monitoring report presents a continuous potentiometric surface for ground water, it is possible that this interpretation of site conditions does not properly account for site-specific conditions that influence occurrence of ground water. The saturated conditions found in surficial materials could actually be present in vertically and laterally restricted lenses that are not hydraulically connected. If so, the presentation of a potentiometric surface map as identified in the annual RCRA ground water monitoring report is not technically justified. The potentiometric surface would actually consist of a number of unconnected, very localized saturated lenses. The validity of both interpretations of the shallow occurrence of ground water is being evaluated in the detailed review of the existing data.

- Unlike other operable units at the RFP, such as Operable Unit 2 (OU2), recent data derived from relogging of cores taken from OU4 boreholes do not indicate the significant presence of Arapahoe sandstones directly in contact with alluvium in the Solar Pond area. There may be no direct hydraulic connection between the alluvium and the Arapahoe sandstone as has been recently evaluated at other locations at the RFP, and earlier speculated at OU4.

The type, quantity, and comprehensiveness of available data is being evaluated and will be used as appropriate to supplement vadose zone investigation activities proposed in this technical memorandum and in the subsequent report.

1.3.2 Other Vadose Zone Investigations

Three vadose zone investigations currently being performed at RFP are briefly described in this section. One investigation is being conducted at two locations under the Sanitary Treatment Plant (STP) sludge drying beds, located just east of Building 995 and east of Building 910. A second investigation is being conducted in the 903 Pad area, and a third investigation is being conducted north of Building 995, just outside the PA. These locations are shown in Figure 1-3.

1.3.2.1 STP Sludge Drying Beds

The primary goal of vadose zone investigations under the sludge drying beds is to determine the potential impact of the sludge drying beds on ground water in the vicinity. This is being conducted by evaluating the hydraulic properties of the soil, soil quality, and the quality of the unsaturated and/or saturated soil water. The implementation of the investigation is being completed in three parts; drilling and sampling of boreholes, installation of monitoring equipment, and vadose zone monitoring.

The investigation is being completed first by sampling soils in six boreholes. The boreholes were drilled at an angle underneath the sludge drying beds to a total depth of 10 vertical feet. Soil samples were collected and analyzed for physical and chemical characteristics. Following drilling and collection of soil samples, three porcelain cup suction lysimeters were installed in two of the boreholes to collect periodic soil-water samples. One lysimeter was placed at the bottom of each borehole, one immediately above it, and another at an elevation just below the bottom of the sludge drying beds. Soil water collected in the lysimeters is being sampled on a monthly basis to establish baseline conditions.

The project has been extended to include a study in the area of the Building 910 sludge drying beds. The Building 910 sludge drying beds are located approximately 40 feet south of Pond 207B-South. The beds have been used for the drying of sanitary sewage sludge to help meet the STP demand. The project will involve the drilling of four boreholes at a 45° angle beneath the beds. The total depth of the boreholes is anticipated to be approximately 8 vertical feet. Two lysimeters will be stacked in two of the boreholes and the other two boreholes will be equipped with neutron probe access tubes. It is anticipated that drilling for this project will begin in December, 1992.

1.3.2.2 903 Pad

Currently, vadose zone soil and soil-water characteristics are being studied in the OU2 area. The primary objective of the study is to evaluate the mobility of plutonium and americium through the vadose zone. The installation of an extensive network of time domain reflectometry (TDR) probes and porous cup samplers within trenches in the study area has recently been completed and is in the process of being calibrated. The information being collected will aid in the OU2 conceptual model for contaminant transport as well as vadose zone mechanisms that will be applicable to other RFP study areas.

1.3.2.3 Recharge Study

A proposed vadose zone investigation southeast of IHSS 165 southeast of the OU6 study area is currently under review. This location is in the manufacturing area east of OU4, northeast of Building 995, and west of the Perimeter Road. The proposed investigation calls for the drilling of borings and the installation of neutron probe access tubes to measure the vertical flux of water in the vadose zone. The investigation will determine if vadose zone water flows to the water table, and will also take into account the affect of natural vegetation, and evapotranspiration, precipitation, and infiltration rates. This investigation will also be an aid in determining local recharge mechanisms.

2.0 TECHNICAL APPROACH

2.1 CONCEPTUAL APPROACH

The vadose zone beneath OU4 is that part of the geologic profile between the ground surface and the top of the water table. The vadose zone investigation is intended to supplement the surface and subsurface investigation work that has been accomplished previously at OU4. In order to maximize the utility of previously gathered data regarding the OU4 subsurface and to efficiently meet the objectives presented in Section 1.2, a decision-based technical approach will be employed. The approach is graphically illustrated in Figure 2-1. In the figure, characterization elements are shown in boxes, and outputs are shown in ovals. Each characterization element and output is numbered. The numbers shown on the illustration correspond to the work element number under which the specific characterization element or output is described in Section 2.2.

Progress to date places the program at partial completion of Work Element 4, formerly a decision point for which the answer was determined to be negative as a result of the initial data review and current understanding of subsurface geology.

Subsurface data previously collected at OU4 have been compiled and reviewed as described in Section 1.3. A summary of the data is listed in Table 1.1 and described in greater detail in Appendix A. Also included in Appendix A is a location map of historical borings in the Solar Ponds area. Detailed data evaluation of these previous data will result in the synthesis of a three-dimensional representation of the subsurface geology at OU4 which will serve as the geologic framework for identifying active vadose zone contaminant transport pathways. The OU4 conceptual model will then be refined based on pathway identification. Information provided in the OU4 Work Plan will be included in the synthesis of the subsurface geologic representation.

Based on the initial representation of the OU4 subsurface geology and identification of vadose zone pathways, it has been determined that the existing data base will not completely support an OU4-specific vadose zone characterization. Extensive hydrologic and geologic data have been collected within the OU4 area. These data are currently being reviewed in detail. Even though much information is available, further specific OU4 data are required. Therefore, an investigative boring program will be implemented according to the Phase I RFI/RI Work Plan. The vadose zone investigation will utilize 16 of the boreholes specified in the Phase I RFI/RI Work Plan, except for 16 additional boreholes required for the two infiltrometer tests, and 25 very shallow borings for Guelph permeameter measurements.

The goals of the drilling program are to define the extent of the vadose zone, to accurately describe vadose zone stratigraphy and lithology, to characterize the chemical and physical properties of vadose zone materials, to make in-situ measurements of physical parameters governing the potential flux of contaminants in the subsurface, and to conceptualize the fundamental approaches to future site monitoring, including potential closure and post-closure monitoring. As the data are processed, the need for additional borings or data will be evaluated and proposed to the agencies, if necessary.

During the vadose zone investigation, direct and indirect monitoring techniques and instrumentation will be evaluated for their applicability to site conditions. The direct monitoring techniques include collection of pore water using Model 1920 or Model 1940 suction lysimeters, depending on capillary pressures and boring depth. Similarly, indirect monitoring techniques including neutron moderation, time domain reflectrometry (TDR) and frequency domain capacitance process (FDC) for measurement of vadose zone moisture will be selected depending on site conditions. Long-term monitoring approaches will be recommended based on the findings of the OU4 vadose zone characterization.

Final output of the vadose zone characterization will include the description of known active vadose zone contaminant migration, and refinement of the OU4 conceptual model which includes potential pathways. The conceptual model will be used in the BRA, in identification of necessary Phase II RFI/RI investigations, and in the evaluation of closure options. The possibility of incorporating the results in a simple numerical model will be investigated.

2.2 SPECIFIC APPROACH

The primary characterization elements depicted in Figure 2-1 are discussed individually in the following subsections. Technical details regarding the theory of the methodologies are generally omitted for brevity. Discussions are included on specific applications of the methodologies to the site and how they meet the objectives of the investigation.

The characterization elements are interrelated and the individual activities should be viewed in the context of the overall program. In some cases, several characterization elements will proceed concurrently, although some elements will need to be performed sequentially, as depicted in Figure 2-1. This phased approach of the overall program will result in optimization of later characterization elements. Even though preliminary progress has already been made through Work Element 4, activities will continue in the preceding work elements in parallel with field activities.

Table 2.1 is a summary of the vadose zone investigation and conveys the estimated scope of field activities. The proposed measuring points were selected on the basis of an initial data evaluation of potential migration pathways. Quantities, depths, and locations of proposed measuring points are provided where appropriate. Such quantification is not appropriate for all elements because of the dynamic nature of the investigation, therefore estimates or estimated ranges are given. The sixteen shallow borings and associated chemical tests on core samples have already been proposed in the OU4 Phase I RFI/RI Work Plan. Sixteen additional borings are proposed for instrument installation at double-ring infiltrometer locations and 25 additional shallow borings for Guelph permeameter measurements. In addition, physical tests on core samples, borehole permeability tests, soil gas surveys, and column leachability tests are proposed. Standard Operating Procedures for all vadose zone investigation activities are included in Appendix B.

Figures 2-2, 2-3, and 2-4 depict preliminary locations for the investigation activities in Table 2.1. These locations were selected to characterize representative conditions within, beneath, and around the ponds, as well as in downgradient areas. Particular emphasis has been placed on seepage locations, surface water quality, pre-construction topography, construction history, and local hydrogeology. Initial findings based on existing information are presented in Appendix A. Specific rationale for the preliminary locations is provided in each of the following subsections. These locations are subject to minor revision if the results of ongoing detailed data review suggest better locations.

2.2.1 Work Element 1 - Evaluate Existing Data

The existing data regarding the RFP in general and OU4 in specific are being evaluated in detail. Due to the large quantity of available information, not all data have been fully evaluated to date. Accordingly, this plan has been prepared following a preliminary review and evaluation of the existing data.

The following types of data are currently being evaluated:

- Geologic maps, cross sections, and reports;
- Historical photographs and stereoscope pairs;
- Piezometric surface maps;
- Soil maps;
- Geotechnical reports;
- Hydrogeologic reports and interpretations;
- Vadose zone monitoring plans and reports;
- Subsurface contaminant distribution maps;
- Ground water monitoring results;
- Boring logs and well installation diagrams; and
- Topographic and other site maps.

The results of this initial data evaluation are summarized in Appendix A. A detailed evaluation of existing data is being conducted in support of the development of a three-dimensional geologic representation of the site. The representation will portray the Solar Pond configuration and the currently known contaminant distribution pattern, allowing for preparation of a detailed working hypothesis regarding vadose zone contaminant transport pathways. The representation will be established and maintained with a Geographic Information System (GIS).

2.2.2 Work Element 2 - Establish Three-Dimensional Geologic Representation

The initial work product of the vadose zone investigation will be the preliminary presentation of the three-dimensional geologic representation of the OU4 area, based on the existing data. The focus of the task will be to arrive at realistic geologic interpretations in order to preliminarily characterize vadose zone migration pathways and to identify data gaps. To aid in this task, EG&G Rocky Flats will develop a bi-directionally linked data base and will use its subcontractor's GIS to store, manipulate, evaluate, and create the three-dimensional geologic representation.

In addition to incorporating existing geologic and hydrogeologic information into the data base and GIS, all construction and as-built engineering drawings of the Solar Ponds and ITS will be included. Any engineering drawings of underground utilities in the OU4 investigation area will be incorporated into the three-dimensional representation.

Detailed cross-sections and fence diagrams will be generated which will graphically depict the subsurface data and interpretations. Contaminant distribution patterns and shallow ground water zones, as well as lithologic classifications, will also be identified. Significant progress has already been made toward a three-dimensional understanding of the sitewide geology.

The geologic representation will be updated to include new data as it becomes available from this and other Phase I RFI/RI investigations at OU4. The geologic representation is not intended to be a predictive model, rather it is designed to fully convey the three-dimensional understanding of complex site geology and to aid in the interpretation of new site data. Accordingly, the representation will continue to represent the overall reference point from which the investigation is driven.

2.2.3 Work Element 3 - Identify Potential Vadose Zone Pathways

Vadose zone migration pathways have been preliminarily identified in order to meet the primary objective of this investigation. In this task, potential migration pathways will be evaluated through analysis of the relationship between the three-dimensional geologic representation, known extent of contamination, contaminant source areas, and other potentially contributing factors such as precipitation events. Transport of solid, liquid, and gas phase contaminants will be considered under both saturated and unsaturated flow conditions in the various media comprising the site vadose zone. A preliminary conceptual model schematic, illustrating potential migration pathways, is presented in Figure 2-5.

Existing OU4 data indicate that surficial materials, and at least some parts of the upper part of the Arapahoe Formation, are unsaturated and could therefore constitute part of the vadose zone. Arapahoe bedrock features such as fractures, buried channels, and multiple ground water zones could have a significant bearing on contaminant transport pathways and the vadose zone water balance. While detailed analysis of available data is continuing, the following potential vadose zone materials must be evaluated since they are known or suspected migration pathways:

- The materials immediately underneath the Solar Ponds are suspected to be the primary pathway that has caused environmental contamination in the area near the Solar Ponds.

- The area within 200 feet north of the Solar Ponds where ground water seepage has historically been and currently is observed could be serving as a pathway for general contamination further to the north.

- A buried topographic drainage channel that trended to the north from an area due north of the berm between Solar Ponds 207A and 207B. This channel is present on photographs taken in 1967, 1971, and 1975, but is no longer apparent due to reworking of the soils during construction of the PA fence. Historical evidence indicates that this channel has been a preferential pathway for saturated flow based on the documentation of ground water seepage in a 1970 geologic and subsoil investigation. Old Trenches 1, 3, and 4 were constructed along the path of this drainage in the 1970s.

- A second buried topographic drainage channel trending northeast from the northeast corner of Solar Pond 207B-North. This channel is present on photographs taken in 1967, 1969, 1971, and 1975, but is no longer apparent due to the reworking of the soils during construction of the PA fence. Historical evidence indicates that this channel has also been a preferential pathway for saturated flow based on the documentation of ground water seepage in a 1970 geologic and subsoil investigation of the Solar Ponds. Old Trenches 2, 5A and 5B were constructed along the path of this drainage in the 1970s.

- A large unsaturated area identified on the potentiometric surface maps of surficial and weathered bedrock lithologies. This area is approximately 200 to 300 feet north of Solar Pond 207C, trends to the east-northeast, and appears to be unsaturated at all times.

- Residual nitrate in soil north of the Solar Ponds acts as a continuing secondary source of contamination to ground and surface water. An analysis of ground water and soil data was the basis for estimating that 60 to 100 tons of nitrate were present in the soils. Only 4 tons of this nitrate were attributable to background concentrations of nitrate. Nitrate concentrations were highest in the surface soil, and 60 percent of the nitrate occurred within 5 feet of the soil surface (Dow Chemical, 1974).

- The results of a boring program to investigate the presence of nitrate contamination near the Solar Ponds indicated that 60 percent of the soil nitrate was present in shallow sand lenses, with the remaining 40 percent present in the less permeable clay lenses or fill materials that underlie the sand lenses. This conceptual model was used to explain the high nitrate concentrations typically observed in North Walnut Creek surface water in the spring. Permeable materials allowed ground water flow during wet periods of the year when the ground water table was elevated, leaching nitrate from the soil. However, during the remainder of the year, when the ground water table was low, and in the less permeable materials, limited movement of the nitrate contamination was observed (Engineering-Science, Inc. 1975).

- In 1988, the evaluation of additional data indicated that elevated nitrate concentrations occurred either at the water table or within the upper several feet of weathered bedrock. Although the water table was often not encountered during drilling, it was concluded that the weathered bedrock had previously been saturated, and that the nitrate previously present in the more permeable surficial materials had been leached from the soil between the mid-1970s and 1987 (Rockwell, 1988).

- Secondary permeability has been identified in the claystones at RFP during the Sitewide Geological Characterization Study, although the influence of secondary permeability on contaminant mobility has not been determined.

Further refinement of the list of potential pathways and characterization of those pathways with parameters such as geometries and flow rates will help determine their relationship to contaminant source areas and overall site hydrogeology.

2.2.4 Work Element 4 - Determine Data Needs

An initial evaluation of existing data has been conducted to provide an understanding of site conditions, and to evaluate deficiencies requiring collection of additional data. Although data evaluation is an ongoing, iterative process, the results of an initial review have identified several potential migration pathways of particular interest. These findings are summarized in Appendix A. Vadose zone monitoring locations have been based on the results of this initial data evaluation. In the event that additional information gathered during the investigation process requires revision of the proposed program, or if access is restricted, appropriate modifications will be proposed. Intervals for conducting field measurements and physical analyses of core samples are designed to complement Phase I RFI/RI chemical sampling intervals, as well as the anticipated nature of physical processes and hydrogeological variability. The currently proposed vadose zone investigation is considered adequate for evaluation of migration pathways, refinement of the water balance, and development of monitoring procedures. Additional characterization, if required, will be conducted under subsequent phases of the OU4 RFI/RI program.

The initial evaluation of existing data, presented in Appendix A, has allowed refinement of vadose zone boring locations previously proposed in the Draft Final version of this documentation. These changes are designed to better characterize potential vadose zone migration pathways. Each of the borings described below will be instrumented with neutron access casings and suction lysimeters following completion. Justification for each change is described below, and revised locations are provided in Figure 2-2. Boring numbers below refer to Figure 2-2.

- Boring location 1 will almost certainly be impacted by OU8 IHSSs. Furthermore, based on the lack of moisture in the propane tank cut, this location will only yield information on a separate flow system from that in the immediate Solar Pond area. This lysimeter will be moved to a location 150 feet to the east in order to characterize a potential pathway from the west half of current 207C pond to the Western Seep, located north of the pond. The west half of 207C pond is also the location of the original clay-lined Solar Pond. This borehole will be placed on or near the 207C berm in order to characterize the upgradient end of this potential pathway for migration. This location for Boring 1, in conjunction with the location for Boring 2, will yield information regarding this potential pathway.

- Boring location 2 will be moved 50 to 100 feet to the northeast in order to be closer to the Western Seep and further from boring location 1. The groundwater should be shallow in this area due to the presence of the Western Seep immediately to the northeast. The lysimeter installation will not be within the seep location since the immediate area near the seep will be saturated. The exact location for this boring will need to be field determined based on moisture from the seep. This change, although minor, will spread out the area covered by vadose zone instrumentation and may help to further characterize the potential pathway of migration to the Western Seep.

- Boring location 3 - no change. This lysimeter location will collect moisture from an area in which Solar Pond 2-Auxiliary had been located. It may be difficult to identify an appropriate location in the field, however, due to the congestion from utilities.

- Boring location 4 will be moved approximately 100 feet southwest so that the lysimeter installation is between the dry end of the Building 779 footing drain and the south end of the Building 779 Footing Drain Seep.

- Boring location 5 - no change.

- Boring location 6 - no change.

- Boring location 7 - no change. This lysimeter installation may collect contaminated moisture due to the presence of numerous original process waste lines in the area.

- Boring location 8 - no change. A field survey will ensure that the location is upgradient (uphill) from the ITS. This lysimeter installation will be near the unsaturated area which has been identified in the annual RCRA groundwater monitoring reports, and will generate valuable data on the moisture present in the unsaturated area.

- Boring locations 9 and 10 - no change.

- Boring locations 11, 12, and 13 are currently depicted in ponds that may not be dewatered or cleaned within the schedule required for this investigation. These locations may need to be angle lysimeter installations from outside the Pond 207B-North and 207B-South berms.

- Boring location 14 has been moved approximately 200 feet to the southeast so that it is immediately upgradient of the unsaturated area which has been identified in the annual RCRA groundwater monitoring reports, and on the buried drainage identified on historical aerial photos. This placement will yield information on the chemical characteristics of moisture in an area at distance from the Solar Ponds. The buried drainage is a suspected preferential pathway for migration.

- Boring location 15 has been moved approximately 160 feet to the northwest. In this location, the lysimeter installation will be downgradient from the ITS in an unsaturated area identified in the annual RCRA groundwater monitoring reports. It will also be located on the buried drainage which is a suspected preferential pathway of migration.

- Boring location 16 - no change. This location, which is immediately east of the drain tile east of the 207B ponds, and immediately west of Building 964, will target another buried drainage present in this general location. Another Phase I RFI/RI boring located on this buried drainage, but not scheduled for vadose instrumentation, has been moved to the northeast to avoid the OU6 triangle area.

2.2.5 Work Element 5 - Implement Boring Program

The Phase I RFI/RI boring program proposed in the Work Plan will be used for vadose zone characterization purposes. Sixteen of the Phase I RFI/RI borings have been selected for vadose zone investigation.

It is currently anticipated that all the vadose zone borehole locations will incorporate a neutron probe access tube. Lysimeters will also be installed at all the vadose zone borehole locations, provided the moisture content is within the range that will permit pore water sampling with a lysimeter. All the proposed vadose zone boreholes, except for the instrumentation boreholes proposed for the double ring infiltrometer tests and shallow holes for Guelph permeameters, will use boreholes identified in the Phase I RFI/RI Work Plan. Boreholes used for vadose zone monitoring purposes will be drilled in the same manner as all other Phase I RFI/RI Work Plan-specified boreholes with the exception of the 16 new boreholes required for the two double-ring infiltrometer tests, and the 25 shallow borings required for Guelph permeameter tests.

The 16 Phase I RFI/RI boreholes used for vadose monitoring purposes will be instrumented with suction lysimeters and neutron moderation access casings to permit pore water sampling and monitoring of soil moisture content. A 2-inch diameter Schedule 40 flush-threaded solid polyvinyl chloride (PVC) casing will be installed for the neutron access tube. A minimum of one suction lysimeter will also be installed in each of these borings. Two vertically-nested lysimeters will be installed in a maximum of eight boreholes encountering an unsaturated thickness of five feet or greater. The lysimeters will have a PVC riser pipe extending to the surface. The boreholes will be backfilled with silica sand, sealed with bentonite, and grouted at the surface to complete the installation.

Minimum historical depth to water in the upper hydrostratigraphic unit will be calculated from existing data and mapped for the study area. One lysimeter will be installed in each boring at a depth midway between the ground surface and historical high groundwater level. For borings encountering an unsaturated thickness of five feet or greater, a second lysimeter will be installed at, or below, the historical high groundwater level. The second, deeper lysimeter will monitor the vadose zone during low water periods, but will be within the water table during high water periods. In this position, the second lysimeter will monitor soils exposed to the influence of seasonally rising and falling groundwater.

In the event that pond cleanout is not accomplished within the schedule required for timely completion of the Phase I RFI/RI, angled boreholes will be drilled in locations adjacent to the ponds. Similar vadose zone instrumentation has been successfully installed in angled boreholes at the RFP Sludge Drying Beds. The maximum angle for effective vadose zone instrumentation is 45 degrees from the vertical. Angled borings are currently being considered for the 207B-North, 207B-South, and 207C Ponds. Although angled borings will characterize the materials at the edges, rather than directly beneath the center of these ponds, sufficient information can be obtained to complete the Phase I RFI/RI investigation within the required schedule.

The 16 instrumentation locations needed for the two double-ring infiltrometer tests will be accomplished either by pushing them in from the surface or installing them in boreholes.

The neutron probe access tubes will be 2-inch diameter PVC casings grouted in a 6-inch augered borehole. The BAT® probe will be pushed from the surface unless site soil conditions require it to be installed in the bottom of an augered hole. It is anticipated that the tensiometers and TDR or FDC probes will be installed in the bottom of a borehole and the borehole grouted to the surface. The shallow Guelph permeameter borings will be hand-augered, if possible, and not be cased or grouted. The double-ring infiltrometer and Guelph permeameter borings will be properly abandoned following completion of testing. The vadose zone investigation activities are summarized in Table 2.1.

2.2.6 Work Element 6 - Characterization of Chemical and Physical Properties of Soils

Soil core samples extracted from the vadose zone investigation borings will undergo initial field screening regarding physical characteristics and for health and safety protocols. Quick-response, portable tensiometers will be used as a field screening technique to measure soil water tension (matric potential) on the extracted soil cores in the field. Radiologic parameters will also be measured as described in OU4 Final Phase I RFI/RI Work Plan, Section 7.3.3.2. Subsequently, the samples will undergo detailed visual inspection during boring log preparation according to EG&G Environmental Management Department (EMD) SOP GT.1. Also, physical testing will be performed on core samples selected to represent the range of variability encountered within the boring program. Physical testing of core samples in the laboratory will provide a series of controlled measurements which can be used to correlate and then extrapolate the results of field testing to the entire Solar Ponds area. A one-foot length of core will be required for the physical tests. The planned number of chemical/physical tests are based upon an average of one sample per six feet of boring depth. Soil sampling protocols are detailed in Section 7.3.3.2 of OU4 Final Phase I RFI/RI Work Plan.

Physical laboratory testing of soil core samples will include the following:

- Particle size sieve and hydrometer tests will be conducted on disaggregated samples to determine the particle size characteristics of the various geologic materials encountered. These analyses will also be used to extrapolate permeability test results over much larger areas based upon use of regression analysis to correlate permeability with grain size distribution.

- Soil water content will be measured in intact cores to correlate field soil water tension measurements with laboratory soil water characteristics curves.

- Bulk density will be determined on intact cores. Measurements will be used with the water content by weight value to determine the water content by volume of selected samples. The bulk density data along with the water content data will allow evaluation of the moisture storage capacity of the vadose zone soils. The storage capacities of the vadose zone soils impact how the vadose zone system behaves.

- Permeability will be used to estimate hydraulic conductivity ranges in specific material types. Permeability or hydraulic conductivity measurements of the intact soil cores are necessary in order to predict the rate of moisture flow in the soils.

- Soil water characteristic curves will be developed for intact cores in the laboratory by measuring the matric potential while varying the water content. These curves will facilitate calculation of unsaturated hydraulic conductivity, which is a critical element for characterizing vadose zone flow of dissolved contaminants.

The physical and hydraulic measurements will be performed on the same core sample. All possible precautions will be taken in the field and laboratory to minimize disturbance of the soil cores, as required by several of the test procedures. A laboratory protocol will be developed which maximizes the utility of each sample without comprising subsequent measurements by altering the physical properties of the sample. For example, a typical soil core will be first weighed at the laboratory. The sample will then be oven dried and weighed to determine the water content and bulk density. Next, after slow saturation, the permeability will be measured using standard laboratory techniques. At the conclusion, the sample will be desaturated using a pressure extraction apparatus to generate a soil water characteristic curve. After the appropriate hydraulic measurements are completed, the sample will be dried and disaggregated so a particle size distribution test can be run.

As defined in the Phase I RFI/RI Work Plan, each of the soil samples collected from RFI/RI borings, which are the same borings as those proposed for this vadose zone investigation, will be analyzed for the following chemical and radionuclide parameters or parameter groups:

- Nitrate;
- Target Analyte List (TAL) metals;
- Uranium 233/234, 235, 236, and 238;
- Plutonium and americium;
- Cesium 137 and strontium 90;
- Gross alpha and gross beta;
- Tritium;
- Target Compounds List (TCL) volatile organics;
- TCL semivolatile organics;
- Inorganics; and
- Pesticides.

Organic carbon content and cation exchange capacity will also be measured on all soil samples. The resulting data will be used in conjunction with the estimated soil-water-gas phase partition coefficients for contaminant components in order to determine the retardation of these compounds in various site geologic materials. This information will be important in establishing fate and transport estimates. Estimation and direct measurement of contaminant partitioning is discussed in further detail below in Section 2.1.13.

2.2.7 Work Element 7 - Borehole Permeability Tests

Borehole permeability data is required to estimate unsaturated hydraulic conductivities, and to support the development of unsaturated zone migration velocities, from which the quantity and direction of contaminant migration can be estimated. Saturated hydraulic conductivities can be used to estimate unsaturated hydraulic conductivity values based on existing theoretical models similar to that presented by Mishra and Parker (1990). Similarly, instrumentation such as the BAT® system can be used to formulate relationships between saturated and unsaturated hydraulic conductivities.

Borehole saturated hydraulic conductivity measurements have been performed at OU1, OU2, in some specific locations at OU4, and at other locations on the RFP. Existing data will be evaluated to determine whether the media tested at the other sites are sufficiently similar to the media at OU4 to warrant inclusion in the OU4 data base. Saturated hydraulic conductivity data at OU4 exist for alluvium, weathered Arapahoe claystone bedrock, and unweathered Arapahoe claystone bedrock. Packer tests were performed (Rockwell International, 1986) at various levels in approximately 18 wells at the RFP; some of the wells (14-86, 15-86, 16-86, 17-86, 22-86, 25-86, 27-86, 32-86) are located within the OU4 area. The results of this previous investigation indicate that the geometric mean for measured hydraulic conductivities is 2×10^{-6} for the Arapahoe sandstone, 5×10^{-7} for weathered Arapahoe claystone, 1×10^{-7} for unweathered Arapahoe claystone, 7×10^{-5} for Rocky Flats Alluvium, and 2×10^{-2} cm/s for valley fill alluvium. Although not all of these results have been validated, they demonstrate the approximate magnitude of hydraulic conductivities in each of these geologic materials.

Borehole permeability or hydraulic conductivity tests will be conducted in the field to provide additional documentation of specific conditions in the Solar Ponds area. Heterogeneities in surficial materials (such as slump features and fill areas) will require site-specific OU4 permeability data to assess the degree of heterogeneities. Permeability tests will be performed in boreholes drilled into the Rocky Flats Alluvium and weathered Arapahoe Formation in order to estimate the ranges in hydraulic conductivities in the various units comprising the vadose zone. The tests will involve the measurement of water inflow rates and pressures into isolated portions of the units of interest.

The BAT® system will be utilized as a borehole permeability test method. The BAT® system is an innovative technique which uses a ceramic cup drive point to make contact with the borehole materials to be tested. The installation can be used for suction lysimetry and tensiometry, as well as downhole permeability testing. In the permeability testing mode, the BAT® system has the added advantage of low water volume introduction into the tested media, which may prove to be important in OU4 site applications.

The BAT® system will be used during the boring program at intervals of approximately five feet, or when units of particular concern are encountered in each borehole. Units of particular concern will be identified in the field by the site geologist based on observation of conditions encountered. Therefore, drilling will be temporarily postponed until a BAT® test is performed and then resumed until the next horizon to be measured is encountered. Further details on the BAT® test are provided in SOP VZ.8.

2.2.8 Work Element 8 - Infiltration, Hydraulic Conductivity, and Storage

The capacity of geologic materials to adsorb, retain, and transmit fluids affects contaminant pathways. Quantitation of the pertinent physical properties of surficial material will be made using information acquired in earlier phases of the investigation, along with additional measurements of permeability, infiltration, water table response, and moisture profiles.

The intent of these measurements is to evaluate the variability of different surficial materials and to estimate: (1) field-saturated hydraulic conductivity; (2) ponded infiltration rates; (3) soil-moisture relationships; and (4) the time required for vadose zone water to reach the ground water table. The scope of these measurements will initially include the unconsolidated Rocky Flats Alluvium.

Permeability

Permeability measurements of the various vadose zone materials are needed in order to predict the quantity and rate of flow. The Guelph permeameters are effective in directly measuring permeabilities of shallow soils (generally less than two feet deep). These shallow soils are subject to heterogeneities caused by differential compaction and disturbance. Shallow soils in the OU4 project area are made up of surface soil disturbed from both natural instabilities and from anthropogenic activities, undisturbed surface soils, fill materials, and differentially compacted materials. Site specific data on material permeabilities must be generated at OU4, and compared with available existing data on similar materials elsewhere at the RFP. Measurement locations will be distributed throughout the OU4 area to document the range of conditions associated with the range of surficial materials present.

Guelph permeameters will be used at approximately 25 locations to characterize the surficial materials, as indicated in Figure 2-3. By measuring permeabilities in both exposed soils and beneath pond liners, conclusions can be drawn regarding current and future infiltration of incident precipitation and ponded water, as well as past infiltration of waste liquids. Measurements will be conducted in soils encountered beneath the pond liner as well as in exposed soils throughout the OU4 area. The resulting permeability data will be geostatistically analyzed to aid in evaluating the variability of hydrologic properties within any single surficial material. The same data will be used to locate representative areas for placement of two planned double-ring infiltrometer tests. Results from the laboratory physical tests, Guelph permeameter tests, borehole BAT® hydraulic conductivity measurements, and double-ring infiltrometer results for each surficial material will be compared to improve the application of OU4 areawide infiltration estimates. Further details on the Guelph permeameters are presented in SOP VZ.2.

Infiltration

Infiltration measurements must be made in the OU4 area in order to support development of the overall vadose zone moisture balance. Infiltration of precipitation is a driving force in the OU4 hydrologic system, and directly relates to the introduction and leaching of contaminants through the vadose zone. Infiltration rates may also be useful in estimating the quantity of contaminants that were introduced to the subsurface from the Solar Ponds during their operation. Additionally, infiltration rates can be related to hydraulic conductivities of the materials if such factors as the hydraulic gradient and extent of lateral flow are known. Infiltration measurements are not known to have been conducted at OU4.

The double-ring infiltrometer tests are proposed to characterize the response of surficial materials in the OU4 area to an induced infiltration event. Locations of these double-ring infiltrometer tests will be based on site slope, soil boring results, presence of caliche zone, Guelph permeameter measurements, and access restrictions. Selection of specific test locations will be based on an analysis of soil type and surface permeability. Locations generally representative of average site conditions will be preferred. Double-ring infiltrometer tests will be monitored through associated shallow borings instrumented with tensiometers and TDR and FDC probes to directly measure soil moisture content.

Tensiometers are used to measure the matric potential of unsaturated soils. Matric potential is the basic driving force of moisture movement in the unsaturated zone and must be evaluated for the determination of the rate of contaminant migration.

The TDR and FDC probes are useful in directly measuring in-situ moisture contents of soils. Measurements conducted during the site investigation will be used to determine which of these two methods will work best for the specific site conditions. The chemistry of the soils in which measurements are being made can affect the performance of these probes. High salinity soils create particular difficulties for both the TDR and FDC probes. Difficulties potentially related to high salinity have been encountered using TDR in other Operable Units at the RFP. The electrical conductivity of saturated soil extracts will be measured in the field to obtain an estimate of soil salinity. Submittal of samples for laboratory analysis of bulk electrical conductivity and major cation composition of soil extract solutions will be considered following the evaluation of the field measurements.

Conceptual diagrams of an infiltration test with associated instrumentation in shallow borings are shown in plan view and cross section in Figures 2-4 and 2-5. Hydraulic conductivities as a function of moisture content can be calculated from information derived from these instrumented double-ring infiltrometer tests. This information can be used during subsequent modeling of flux and monitoring of soil moisture contents, measured by indirect means, to infer pore liquid mobility. Neutron moderation monitoring techniques will also be calibrated during the infiltration tests and used to monitor and quantify the propagation of wetting fronts. Direct measurement of the unsaturated hydraulic conductivity/pressure head relationship will also be attempted using the BAT® system.

Water Table Response

Four existing monitoring wells will be equipped with transducers within the uppermost water-bearing zone. Integrated travel time from the ground surface to the water table will be estimated by comparing water table fluctuations with precipitation or snow melt events. Efforts will be made to correct for atmospheric pressure changes. This will provide a means of understanding the dynamic nature of the vadose zone water table interface and related implications for the potential for leaching of contaminants. Procedures for transducers in wells are presented in SOP VZ.5.

Moisture Profiles

Readings from neutron logging of hydrogen-bearing materials in the subsurface are related to moisture content of those materials. The soil moisture provides a measure of moisture content as a function of depth. Repeated logging of boreholes will reveal the movement of wetting fronts through the soil column, which will be used to estimate fluid transmission rates. Neutron logging is not applicable for near-surface measurements due to surface boundary interferences.

Neutron logging will be performed in boreholes to generate empirical estimates of fluid transmission rates as discussed in Section 7.3.2 of the OU4 Final Phase I RFI/RI Work Plan. Neutron logging of the cased vadose zone boreholes will be conducted on a weekly basis, initially, and later on a monthly basis. The frequency of logging may be increased following heavy precipitation events, particularly during the spring thaw and following early summer thunderstorms. Existing monitoring wells located in areas of hydrogeologic interest will also be used for neutron logging. Procedures for neutron moisture logging are detailed in SOP VZ.7.

2.2.9 Work Element 9 - Incorporate Data into Three Dimensional Geologic Model

The data collected in Work Elements 5 through 8 will be incorporated into the three-dimensional geologic representation (Work Element 2) of the subsurface at OU4 as described in Section 2.2.2. The resulting clarification of the subsurface geology will be used to enhance identification of potential vadose zone contaminant migration pathways (Work Element 3) as described in Section 2.2.3.

The investigation will proceed to calculation of a vadose zone water balance, Work Element 10, and the adequacy of the data collected will be evaluated. If data collected do not satisfy objectives of the program, supplemental information needs will be identified and proposed. If appropriate, the investigation will return to Work Elements 5 through 9 in subsequent investigation phases, such as the Phase II RFI/RI.

2.2.10 Work Element 10 - Conduct Water Balance

Water balances have previously been conducted at RFP as part of the Zero Offsite Water Discharge Study. Task 11/13 of this past investigation produced an overall water balance for the plant, while Task 7 produced a water balance specific to the Solar Ponds ITS (ASI, 1991). The current investigation will serve to expand understanding of the storage and transmission properties of the vadose zone.

The infiltration of water or liquid contaminants can activate vadose zone transport pathways when inputs exceed the storage capacity of the surficial material. A water balance will provide an estimate of the magnitude of past, present, and future vadose zone fluxes. Appropriate precipitation, evaporation, transpiration, and run-off data are available from previous on-site measurements and other published sources (ASI, 1991). The water balance will infer the volume of water which has, is, or will migrate through the vadose zone by subtracting known outputs and estimated storage increases from known or estimated inputs. The water balance will be approached as a cascade-type compartment model wherein the uppermost unit will be considered first. At a minimum, the following methods will be used:

- Estimation or measurement of past, present and future inputs including precipitation, surface water inputs, Solar Pond leakage, and ground water influx;
- Estimation or measurement of past, present, and future outputs including surface runoff, interceptor trench output, and evapotranspiration; and
- Estimation of historical and current storage capacity and moisture content levels in the surficial materials beneath OU4 based on information from previous elements in this investigation.

Figure 2-6 schematically illustrates the boundaries of the water balance.

The goals of the water balance will be threefold: (1) estimate the magnitude of past, current, and future contaminant mobilization along vadose zone transport pathways; (2) quantify the efficiency of the ITS; and (3) assess the likelihood of future flow events exceeding the design capacity of the ITS. The water balance will also assist in evaluating the effectiveness of proposed future engineering options such as infiltration caps, new or redesigned interceptor drains, grout curtains, or other options.

2.2.11 Work Element 11 - Pore-Liquid Chemistry

Contaminants present in pore liquids, but not adsorbed or held tightly in thin liquid films on solid particles, represent the potentially mobile liquid fraction. Before advective transport can occur, pore liquid volume must also be high enough that matric forces are overcome. Diffusive transport occurs when significant chemical concentration gradients are present.

Lysimeters will be used for investigating pore liquid chemistry. Liquids collected directly through lysimeters installed in borings will be used to detect mobile contaminants and characterize pore liquid migration. Lysimeters also permit monitoring of pore-liquid water quality through time at a single location, allowing seasonal or long-term transport trends to be identified through an ongoing monitoring program. Additional analyses will be conducted if sufficient sample volume can be collected. A logic diagram indicating procedures to be followed for installation of lysimeters is included as Figure VZ.10-1.

Up to 24 lysimeters will be used in the 16 vadose zone boreholes. The lysimeters will be installed parallel to the neutron probe access tube in each vadose zone borehole. Procedures for lysimeter installation and sampling are presented in SOP VZ.10.

Pore liquid samples will be analyzed for the following chemical and radionuclide parameters or parameter groups:

- Nitrate;
- Specific conductance;
- Target Compound List (TCL) volatile organics;
- pH;
- Target Analyte List (TAL) metals;
- Uranium 233/234, 235, 236, and 238;

- Plutonium and americium;
- Cesium 137 and strontium 90;
- Gross alpha and gross beta;
- Tritium;
- TCL semivolatile organics;
- Inorganics (major anions and cations); and
- Pesticides.

While every effort will be made to collect sufficient sample volume to obtain a complete water analysis, it is unlikely that a sufficient sample volume to conduct all of the desired analyses will be available under field conditions. If sufficient sample quantity is not available, the analytical suite will be prioritized in the order listed above. At a minimum, nitrate, specific conductance, TCL volatile organics, and pH will be analyzed in pore water from each lysimeter. A composite sample may be required to ensure sufficient volume for determination of the remaining analytes.

2.2.12 Work Element 12 - Characterize Soil Gas

Soil gas may contain fractions of volatile contaminants indicative of vapor phase transport within the vadose zone. Major gases such as oxygen, methane, and carbon dioxide can indicate interaction of infiltrating contaminants with natural soil materials, and progressive degradation of organic and inorganic contaminants may be characterized by the type and concentration of gaseous species present. Volatile organic compounds indicate the presence of contaminants in either the vadose zone or the underlying saturated zone, or both.

Objectives of the soil gas survey include:

- Identification of volatile organic compounds potentially associated with wastes disposed in the original Earthen Ponds;
- Identification of potential volatile organic compound contribution to OU4 ground water originating from upgradient sources; and
- Characterization of major gases around the 207B series ponds.

The soil gas survey is intended to characterize the general composition of soil gas in the OU4 area, rather than identify specific source areas and migration pathways. Since historical data suggest that volatile organic compounds are absent over most of the OU4 area, the soil gas measurements will serve to verify these previous observations. Measurement of major gas composition near the 207B series ponds may provide insight regarding the source of trapped gases beneath the 207B-South pond liner.

A preliminary soil gas survey using a limited number of sampling points at OU4 will be implemented, followed by more complete surveys if initial results reveal the presence of widespread volatile organic compounds. The suite of gas analytes will include volatile organic compounds used in industrial operations at RFP and suspected to be present in the Earthen Ponds and upgradient areas to determine potential source contributions. These analytes will include carbon tetrachloride, tetrachloroethylene, trichlorethylene, and trichloroethane. In addition, major gases such as oxygen, carbon dioxide, and methane will be measured in the 207B series pond area. Characterization of major gas distributions in the subsurface will be used to identify regions of geochemical or biochemical activity in the subsurface and to estimate the redox state of soils in the contaminated zone.

The survey design will include twenty-eight measurement points. Preliminary locations are presented in Figure 2-2. Sixteen locations have been initially identified for the Earthen Ponds area, four locations identified in the upgradient area, and eight locations around the 207B series ponds. Additional samples may be sited based on initial results if field determinations indicate the presence of volatile organic compounds.

The soil gas samples will be obtained by driving a perforated probe into the ground and applying a vacuum. This procedure is described in EMD SOP GT.9. The soil gas samples will be analyzed using a field gas chromatograph or infrared spectrometer. An all-terrain vehicle-mounted or truck-mounted Geoprobe® or similar device will be used to perform the survey.

2.2.13 Work Element 13 - Estimate Contaminant Partitioning

In general, contaminants distributed in the subsurface may be partitioned among the following phases:

- dissolved contaminants in aqueous solution;
- contaminants sorbed onto the surface of soil particles and organic matter; and
- contaminants in the gaseous phase.

This element of the work plan will consist of estimating the distribution of contaminants, by phase, in the OU4 subsurface. Data from previously completed elements of the vadose zone investigation will be compiled in order to develop a site-wide estimate of the degree and extent of contaminants in the various phases at the site. Distribution of contaminants in the fixed soil, mobile gas, and aqueous phases will be used to assess contaminant mobility and to evaluate potential remedial alternatives.

Dissolved contaminant levels will be estimated based on data generated during the soil pore-liquid sampling effort (Work Element 11). Contaminant levels in the gaseous phase will be estimated from the measurements made during the soil gas characterization effort (Work Element 12). Total contaminant levels will be measured on soil samples collected during the soil sampling activities (Work Elements 5 through 8). Data available from other OU4 investigations will be incorporated and compiled to augment the data base. The final output will be a graphic and tabular presentation of the data, and a description of the contaminant phase distribution among solid, liquid, and gas phases at OU4. The contaminant phase distribution description will be categorized into general inorganics, metals, radiologic parameters, and volatile organic compounds, as availability of field data allow.

Because of uncontrolled field variability, potential sampling errors and bias, time dependence of contaminant phase equilibria, and the necessary assumption that contaminant partitioning in the field has reached an equilibrium point, the resulting calculations and presentation of the contaminant phase distribution will necessarily be an estimate of the true condition which exists at the site at any given time. In order to assess these properties under more controlled conditions, field estimates of contaminant distribution among aqueous, solid, and gaseous phases will be compared to literature descriptions and laboratory measurements of contaminant partitioning. Review of contaminant behavior, as described in terms of physical-chemical characteristics and empirical observations of behavior of other sites, will be developed from the literature. Literature investigations will be particularly important in documenting the phase distribution and behavior of strongly adsorbed contaminants such as plutonium and americium. In addition, data generated under OU2 regarding the mobility of plutonium and americium in RFP soil will be reviewed. Column leaching tests using contaminated soils will also be conducted to assess the mobility of nitrate and estimate the relative volume of infiltrating water required to flush this relatively mobile contaminant from soils. Leaching solutions will approximate the composition of rainwater to simulate natural infiltration conditions. Analysis of the leachate for nitrate, as well as pH, major cations and anions, and possibly metals, will be conducted. Approximately 10 core samples of shallow soils collected within the OU4 area will be used for these column leaching tests. Sample locations will be distributed throughout surficial materials encountered in the pond area and the downslope ITS area.

The resulting estimate of contaminant distribution by phase in the subsurface will be highly useful in developing the understanding needed to proceed to the final work elements of the work plan, refining the OU4 conceptual model of significant vadose zone migration pathways, and in developing monitoring approaches which may prove useful during closure and post-closure of the site. Knowledge of the relative mobility of contaminants, in combination with an understanding of vadose zone hydraulic conditions, will allow estimation of vadose zone contaminant transport under both existing and hypothetical scenarios. Development of predictive capabilities, such as determination of the influence of increased or decreased infiltration or the mobility of contaminants with widely differing properties, will be essential in evaluating remedial alternatives. Comparison of field, literature, and laboratory measurements will aid in assessing the accuracy and representativeness of these different evaluation procedures in describing actual field conditions.

2.2.14 Work Element 14 - Characterization of Vadose Zone Pathways

Compilation, evaluation, and interpretation of site data will result in refinement of the OU4 conceptual model of vadose zone transport pathways. The deliverable products from this element include:

- A narrative description of the conceptual model of vadose zone transport pathways at OU4;
- A listing of vadose zone transport pathways at the OU4 site within each geologic unit, specifying pathway type, flux, contaminants, and locations or orientations;
- A discussion of the interrelationship of different pathways with particular emphasis on the possibilities for preferential flow paths; and
- Three-dimensional graphic representations of the site vadose zone and the interrelationship of identified migration pathways.

Available vadose zone transport models will also be reviewed to determine suitability of individual transport codes to simulate the conditions observed in the OU4 area. To date, vadose zone transport models fall significantly short of providing acceptable predictive capabilities. Long-term empirical monitoring may prove to remain the preferred option.

This deliverable will fulfill the objective of the investigation by providing a characterization of the active vadose zone migration pathways at OU4 and by guiding the development of monitoring approaches.

2.2.15 Work Element 15 - Develop Monitoring Approaches

Long-term monitoring approaches, to be effective, must be tailored to the potential vadose zone migration pathways identified in the OU4 conceptual model. Deliverable products from this step will be include the following:

- A narrative description of an overall monitoring strategy for the site; and
- A plan for testing the effectiveness of proposed techniques at the site.

2.3 DATA QUALITY OBJECTIVES

Data Quality Objectives (DQOs) have been developed for the collection of field data generated during the vadose zone investigation portion of the Phase I RFI/RI investigation. The DQOs discussed in this technical memorandum are in addition to Section 4.0 of the Final OU4 Phase I RFI/RI Work Plan.

Vadose zone investigation will be used to refine the existing water balance and develop an understanding of water flow and contaminant migration from suspected source areas. Vadose zone transport pathways, including type, contaminants, relative flux, and locations or orientations will be developed. The relative effectiveness of the various techniques implemented during the investigation will be considered in developing long-term monitoring strategies.

The proposed field sampling and analysis program for the vadose zone investigation will generate a comprehensive set of data types, field observations, field measurements, and laboratory analytical results. Data types will include:

- Laboratory physical and chemical testing; and
- Field instrumentation designed to determine the physical, fluid storage, and fluid transmission properties of the vadose zone.

Sampling and measurement locations have been based on the initial evaluation of existing data. Boring locations, originally selected in the Phase I RFI/RI Work Plan (EG&G, 1992a), have been modified on the basis of this existing data review. This biased sampling approach was designed to characterize suspected transport pathways. Specifically, the following factors related to migration pathways in the subsurface have been considered:

- Historical descriptions of pond configuration and operation;
- Field documentation of groundwater seepage on the hillside north of the ponds;
- Seepage water quality;

- ITPH construction details;
- RCRA groundwater monitoring results;
- Surface water drainage features;
- Site hydrogeology; and
- Pond cleanout schedule.

Field measurement and sampling intervals have been designed to correspond with approved chemical sampling intervals, while characterizing the anticipated variability in vadose zone conditions.

The proposed use of each type of information will dictate the level of data quality required for that measurement. The EPA has defined five levels of quality for analytical data. Each data quality level is defined in Section 4.2.3 of the Final OU4 RFI/RI Work Plan. Analytical levels II, III, IV, and V will be used during the implementation of the vadose zone investigation and correspond to the following:

- Level II - Field testing;
- Level III - Geotechnical and physical testing;
- Level IV - Offsite chemical analysis; and
- Level V - Offsite radiochemical analyses.

Site-specific data quality objectives are summarized in Table 2.2. SOPs for any activities conducted which currently are not addressed in the EMD Operating Procedures will be developed and approved. Drafts of the above mentioned SOPs are presented in Appendix B.

3.0 SCHEDULE

The Field Sampling Plan (FSP) of the OU4 Final Phase I RFI/RI Work Plan divides field work into separate geographic regions which have been defined as follows:

- Interceptor Trench System (ITS) - The area outside the PA, which encompasses most of the ITS;
- Around Ponds - The area inside the PA, excluding the pond regions;
- Pond 207A - The area encompassing Pond 207A and its berm;
- Pond 207B-North - The area encompassing Pond 207B-North and its berm;
- Pond 207B-Center - The area encompassing Pond 207B-Center and its berm;
- Pond 207B-South - The area encompassing Pond 207B-South and its berm;
- Pond 207C - The area encompassing Pond 207C and its berm; and
- Earthen Ponds - The area encompassing the three earthen ponds used during the period of December 1953 to June 1960. These ponds were designated as Pond 2, Pond 2-Auxiliary, and Pond 2D, but shall be referred to as the Earthen Ponds in this document.

The primary activities in each of these areas for the Phase I RFI/RI at OU4 include borehole installation, subsurface soil sampling, borehole permeability testing, and installation of equipment to estimate the capacity of geologic materials to adsorb, retain, and transmit fluid. It is estimated that approximately one month will be needed to perform these activities in each area. An additional year may be needed for monitoring data collection. The entire duration of the vadose zone monitoring for OU4 will initially parallel the Phase I RFI/RI schedule, which is being updated and maintained separately. A detailed schedule for vadose zone investigation activities is provided in Appendix C.

Related to the vadose zone investigation schedule are the process and schedule of other investigations in the vicinity of OU4, especially the Solar Ponds cleanout program being conducted by Halliburton/NUS. Specifically, the ponds must be cleaned out before drilling equipment can be moved onto the pond floor and vertical drilling through the pond liners can start. In addition, pond cleanout equipment located immediately adjacent to the ponds may also have to be moved before drilling around ponds can be completed. If necessary, angle and horizontal boring will be considered as a means of addressing schedule conflicts. A separate technical memorandum is planned as a contingency to specify the angle and horizontal boring alternatives.

4.0 REFERENCES

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TABLE 1.1

SUMMARY OF BOREHOLE INSTALLATIONS FOR INVESTIGATION/MONITORING OF THE SOLAR PONDS - OU4

Date	No. of Boreholes	Data Source*
1954	1	Waste Disposal Coordination Group Monthly History Reports
1960	6	Waste Disposal Coordination Group Monthly History Reports
1966	2	Waste Disposal Coordination Group Monthly History Reports
1970	10	Geological and Subsoil Investigations at the Evaporation Ponds - Woodward-Clyde & Associates for Dow Chemical Company
1971	1	Map of Existing Wells from 1986 Solar Pond RCRA Permit Application
1974	56	Nitrate Inventory North of Solar Evaporation Ponds - Dow Chemical Company
1975	31	An Engineering Study for Water Control and Recycle Supplemental Report - Engineering-Science for AEC/RFAO
1986	22	1986 RCRA Part B Permit Application for Rocky Flats, Part E
1987	17	1988 Solar Pond RCRA Closure Plan, Appendix 6 Hydrogeologic Characterization Report
1989	32	Sitewide Geological Characterization Program Phase I
1991/1992	4	Sitewide Geological Characterization Program Phase II
TOTAL	182	

*References and descriptions of these data collection efforts are included in Appendix A.

TABLE 2.1
VADOSE ZONE INVESTIGATION SUMMARY

FLOW CHART ELEMENT	DESCRIPTION	QUANTITY (*NOTE)	ESTIMATED DEPTH (FT.)	TARGET HORIZON	METHOD
5	SHALLOW BORINGS (PHASE I RFI/RI WORK PLAN)	16	5-20	ALLUVIUM AND/OR WEATHERED ARAPAHOE	HOLLOW STEM AUGER NEUTRON PROBE AND LYSIMETER
6	PHYSICAL TESTS ON CORE SAMPLES	50 (*6)	VARIOUS	ALLUVIUM AND/OR WEATHERED ARAPAHOE	OUTSIDE LABORATORY
6	CHEMICAL TESTS ON CORE SAMPLES (PHASE I RFI/RI WORK PLAN)	50 (*6)	VARIOUS	ALLUVIUM AND/OR WEATHERED ARAPAHOE	OUTSIDE LABORATORY
7	BOREHOLE PERMEABILITY TESTS	32-48 (*1)	VARIOUS	ALLUVIUM AND/OR WEATHERED ARAPAHOE	BAT® SYSTEM
8	GUELPH PERMEAMETER MEASUREMENTS	25 (*2)	0-2	ALLUVIUM	GUELPH PERMEAMETER IN BORINGS
8	DOUBLE-RING INFILTROMETER	2 (*3)	SURFACE	ALLUVIUM	INFILTROMETER
8	INSTRUMENT BORINGS FOR DOUBLE-RING INFILTROMETER TESTS	16 (*2)(*4)	2-15	ALLUVIUM BELOW INFILTROMETERS	AUGER BORINGS, TENSIOMETERS, TDR, FDC, NEUTRON PROBE
8	TRANSDUCERS IN EXISTING PIEZOMETERS	4-8	VARIOUS	VARIOUS	TRANSDUCERS AND DATA LOGGERS
11	PORE WATER	up to 24	5-20	ALLUVIUM AND/OR WEATHERED ARAPAHOE	CERAMIC LYSIMETERS
12	SOIL GAS SURVEY	28 (*5)	3-15	UPGRADIENT, EARTHEN PONDS AND B-SERIES PONDS	DRIVEN PROBE ANALYZED FOR VOCs AND MAJOR GASES
13	COLUMN LEACHABILITY TESTS	10 (*7)	VARIOUS	ALLUVIUM AND/OR WEATHERED ARAPAHOE	OUTSIDE LABORATORY

(*1) ASSUME AVERAGE OF TWO TO THREE TESTS PER BORING
(*2) NEW BORINGS NOT IN WORK PLAN
(*3) ASSUMES 2 TESTS IN THE SHALLOW UNCONSOLIDATED MATERIAL
(*4) 8 INSTRUMENT BORINGS PER INFILTROMETER
(*5) 28 SHALLOW SAMPLES FROM DRIVE POINTS 3 TO 15 FEET DEEP
(*6) ESTIMATE BASED ON AVERAGE 6-FOOT SAMPLE INTERVAL IN PHASE I RFI/RI WORK PLAN BORINGS WITH AN AVERAGE DEPTH OF 20 FEET

TABLE 2.2
DATA QUALITY OBJECTIVES FOR VADOSE ZONE CHARACTERIZATION

Objective	Data Type	Sampling/Analysis Activity	Analytical Level
a) Characterize Vadose Zone Physical/Lithologic Properties	Physical Testing	Conduct laboratory geotechnical tests which will include: • particle size/hydrometer tests (sec. 2.2.6) • organic matter content (sec. 2.2.6) • lithologic logging of continuous samples from boreholes (sec. 2.2.5)	III
b) Characterize Vadose Zone Storage Properties	Physical Testing	Conduct laboratory geotechnical tests which will include: • bulk density (sec. 2.2.6) • soil water content (sec. 2.2.6) • soil water characteristic curves (sec. 2.2.6)	III
	Field Testing	Install instrumentation and conduct field testing using: • tensiometers (sec. 2.2.8) • neutron logging (sec. 2.2.8)	II
c) Characterize Vadose Zone Transmission Properties	Physical Testing	Conduct laboratory geotechnical tests which will include: • particle size/hydrometer tests (sec. 2.2.6) • permeability tests (sec. 2.2.6) • soil water characteristic curves (sec. 2.2.6)	III
	Field Testing	Install instrumentation and conduct field testing using: • double-ring infiltrometer (sec. 2.2.8) • BAT® System tests (sec. 2.2.7) • transducers (sec. 2.2.8) • Guelph permeameters (sec. 2.2.8) • time domain reflectometry (TDR) (sec. 2.2.8) • frequency domain capacitance (FDC) (sec. 2.2.8)	II
d) Characterize Vadose Zone Chemical Parameters	Chemical Testing	Conduct laboratory chemical analyses which will include: • chemical/radionuclide parameters (sec. 2.2.6) • specific conductance (sec. 2.2.11)	IV and V
	Field Instrumentation	Install instrumentation and collect samples using: • soil gas probes (sec. 2.2.12) • lysimeters (sec. 2.2.11) • bulk electrical conductivity (sec. 2.2.8)	II, III

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Figure 1-1
OU4 Site Photograph
June 6, 1991

CHECKED BY	APPROVED BY	DRAWN BY JAA	DATE 10/12/92	FILE NAME 40104\F03-102.DWG	REVISION NO. 0

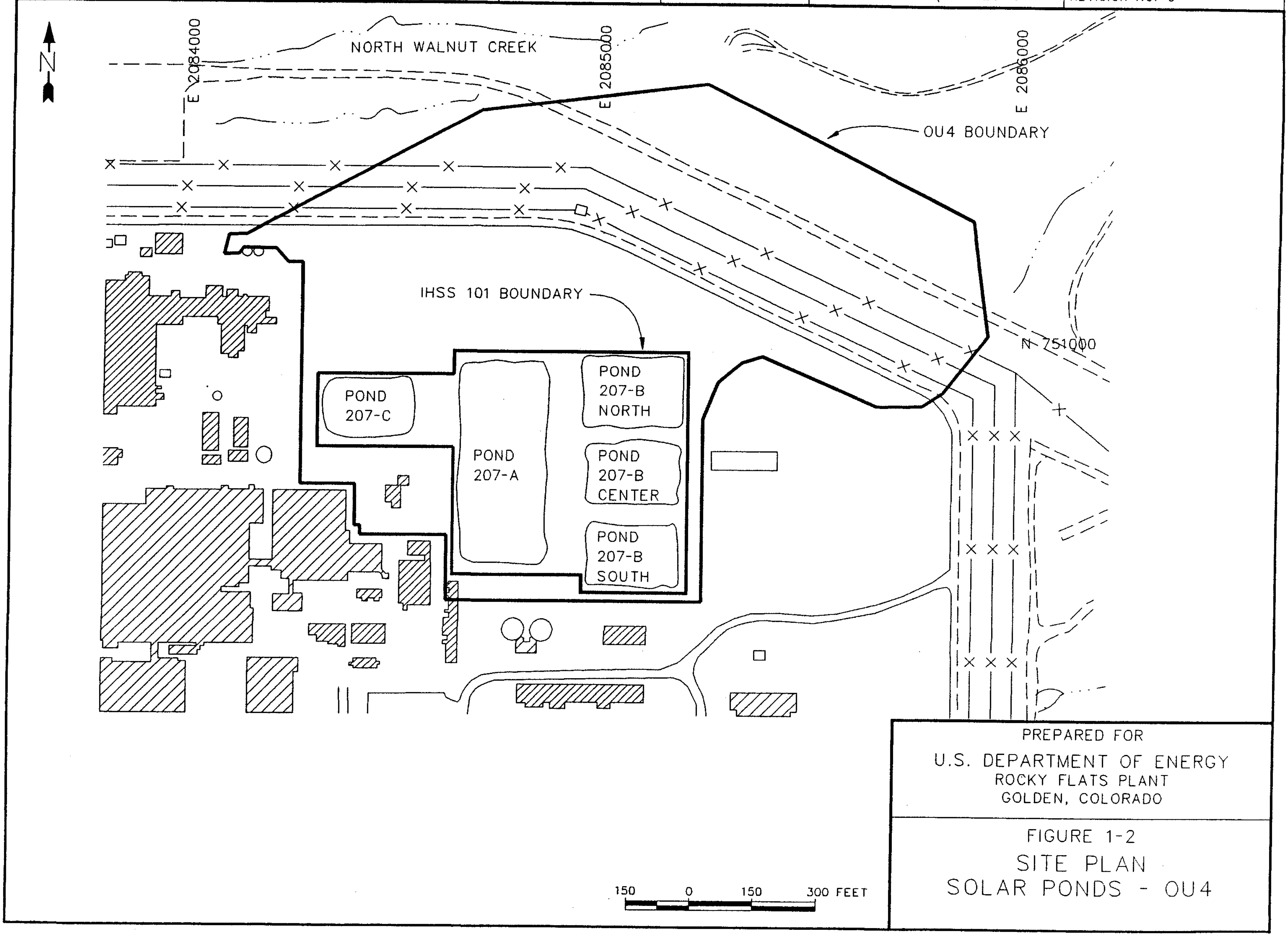

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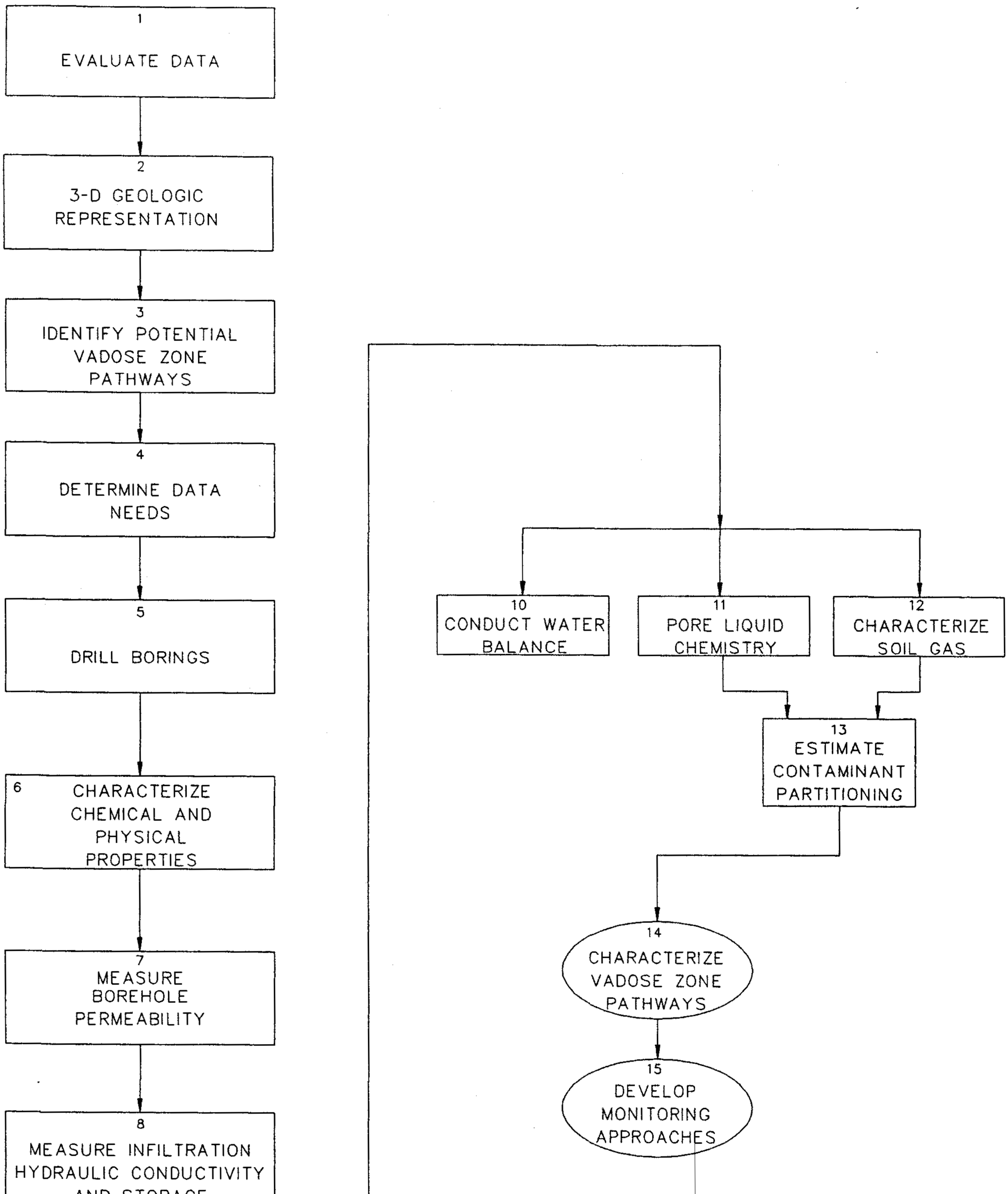
FIGURE 1-2
SITE PLAN
SOLAR PONDS - OU4



REVISION NO. 0
FILE NAME 40104\F05-001.DWG
DATE 12/11/92
DRAWN BY EMH
APPROVED BY
CHECKED BY

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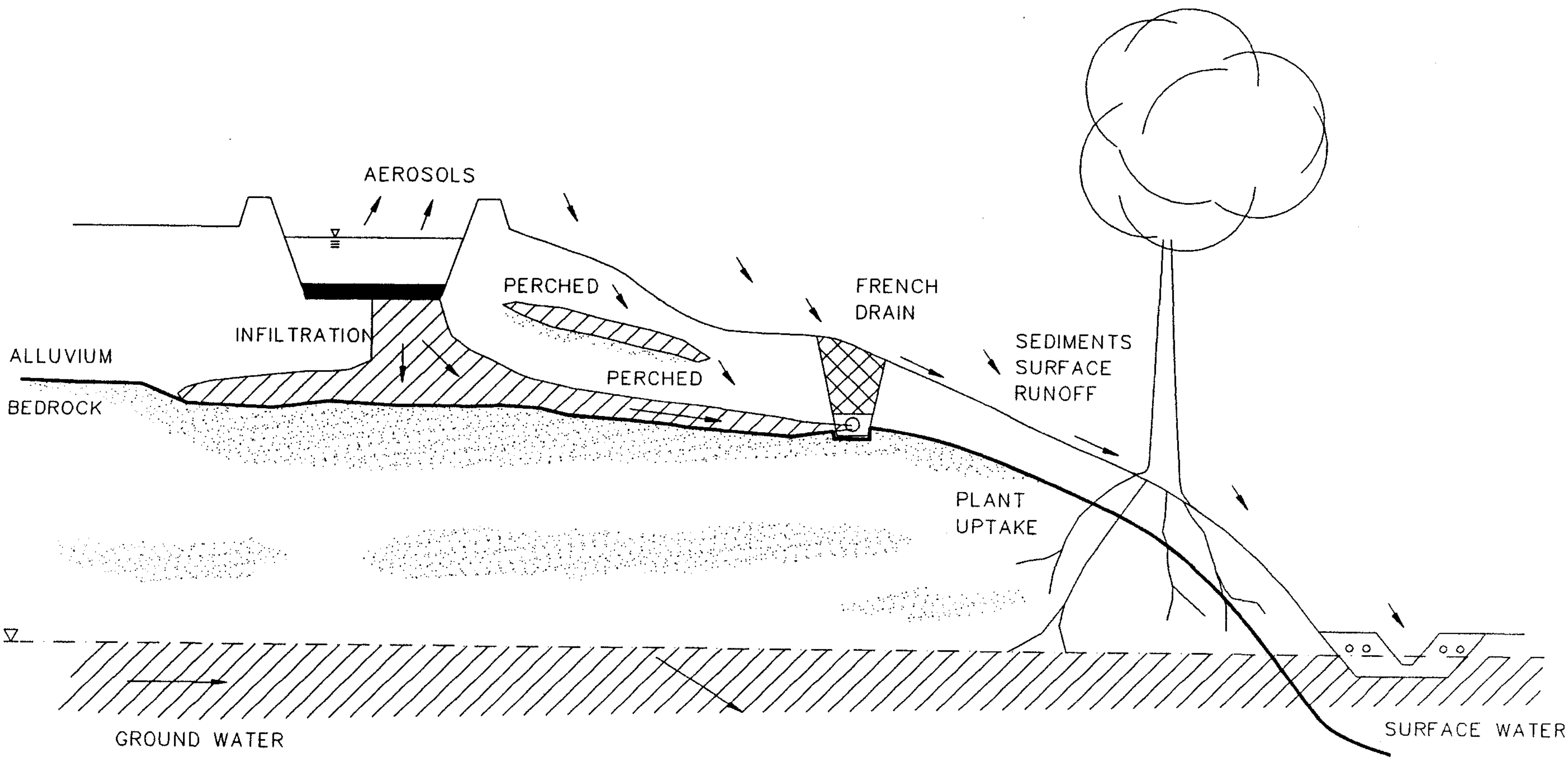
FIGURE 2-1
TECHNICAL APPROACH
CHARACTERIZATION ELEMENTS
SOLAR PONDS - OU4

CHECKED BY	APPROVED BY	DRAWN BY EMH	DATE 12/11/92	FILE NAME 40104\F05-002.DWG	REVISION NO. 0



EXPLANATION

POTENTIAL POND LEAKAGE, PERCHED ZONES, AND GROUND WATER

CLAY LENSES/LAYERS RESTRICTING VERTICAL MOVEMENT

MODIFIED FROM FIGURE 2-31 OF THE SOLAR PONDS PHASE I RFI/RI WORK PLAN

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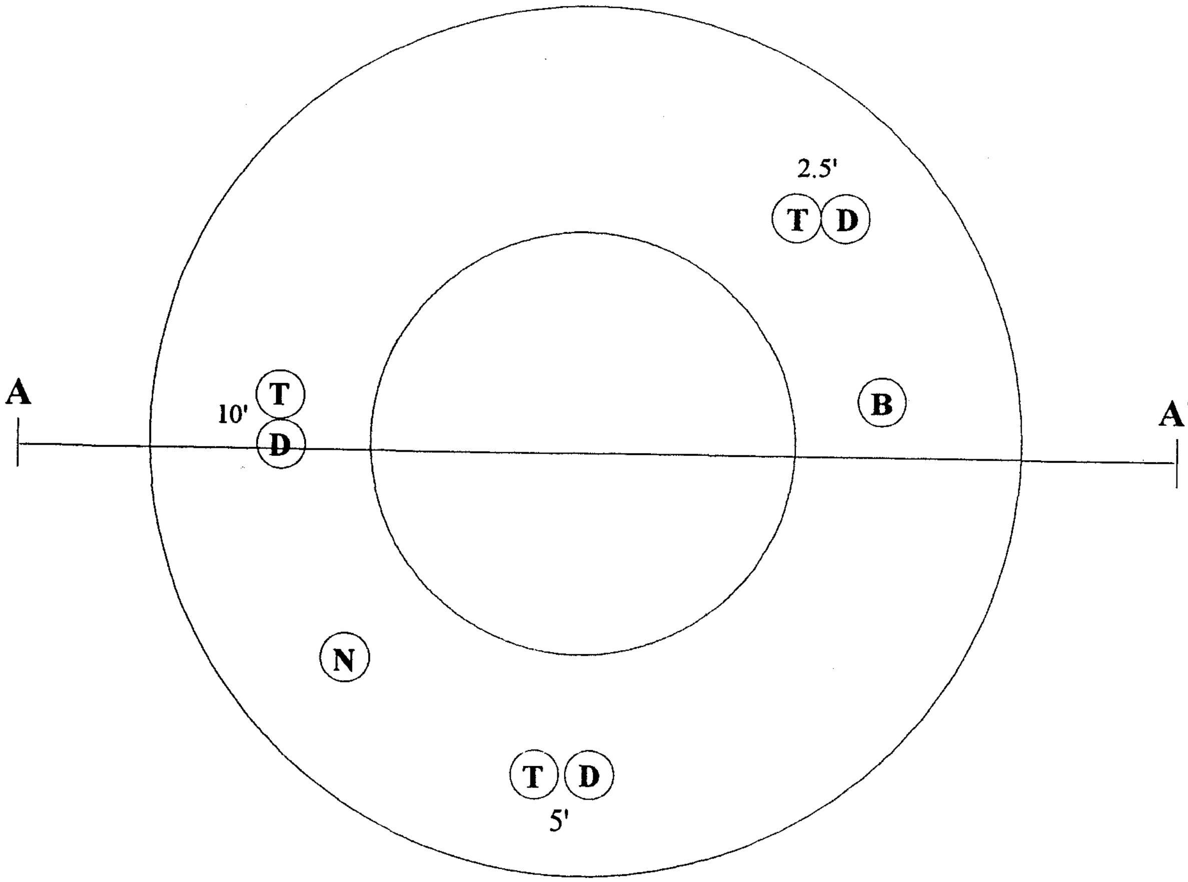
FIGURE 2-5
OU4 CONCEPTUAL MODEL
SOLAR PONDS - OU4



(N) = Neutron Probe/FDC Access Tube

(T) = Tensiometers

(D) = TDR Probes

(B) = BAT Probe

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Figure 2-6
SCHEMATIC OF INFILTRATION TESTS - PLAN VIEW
SOLAR PONDS - OU4

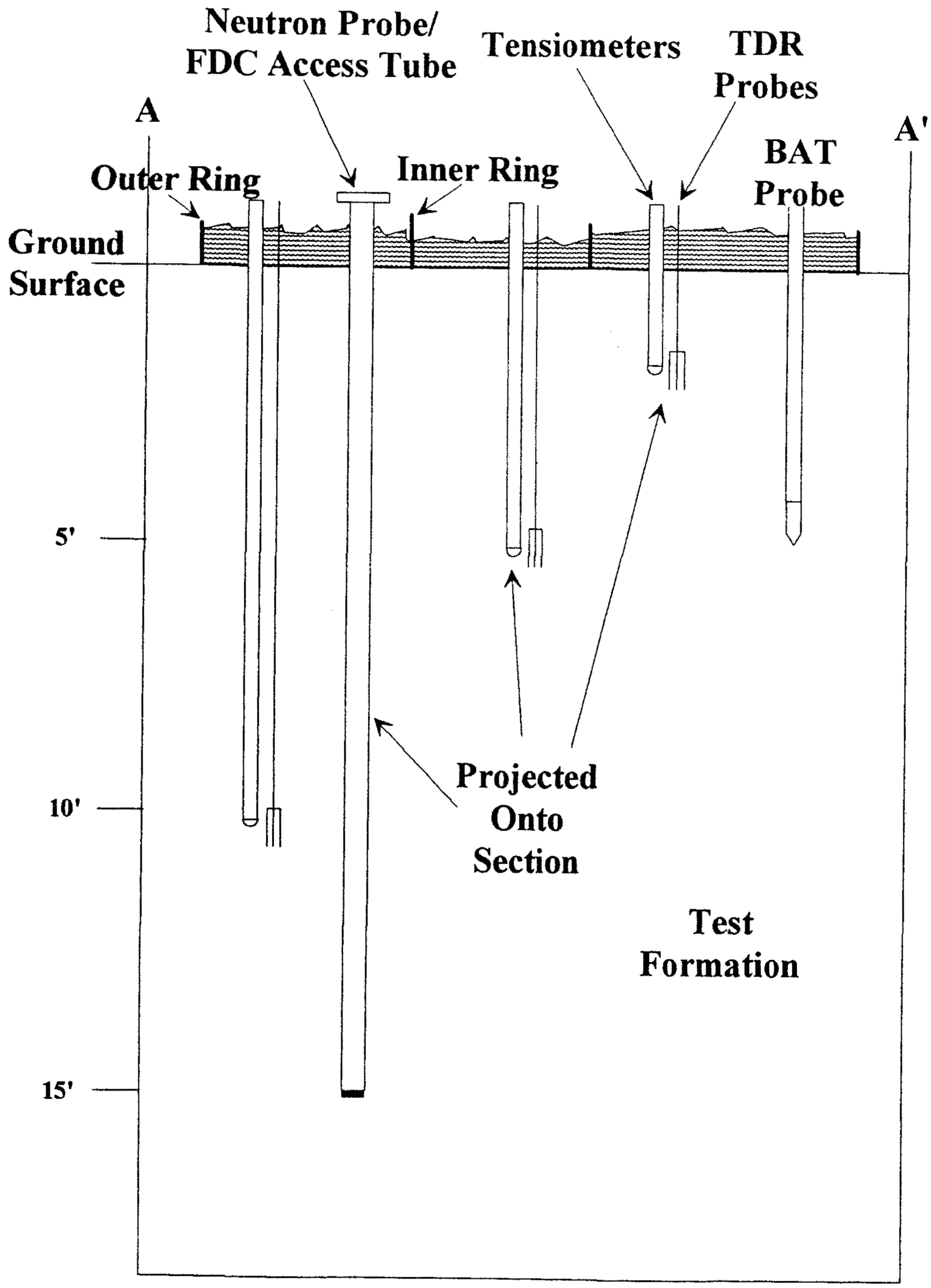

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Figure 2-7
SCHEMATIC OF INFILTRATION TESTS-
CROSS SECTIONAL1 VIEW
SOLAR PONDS - OU4

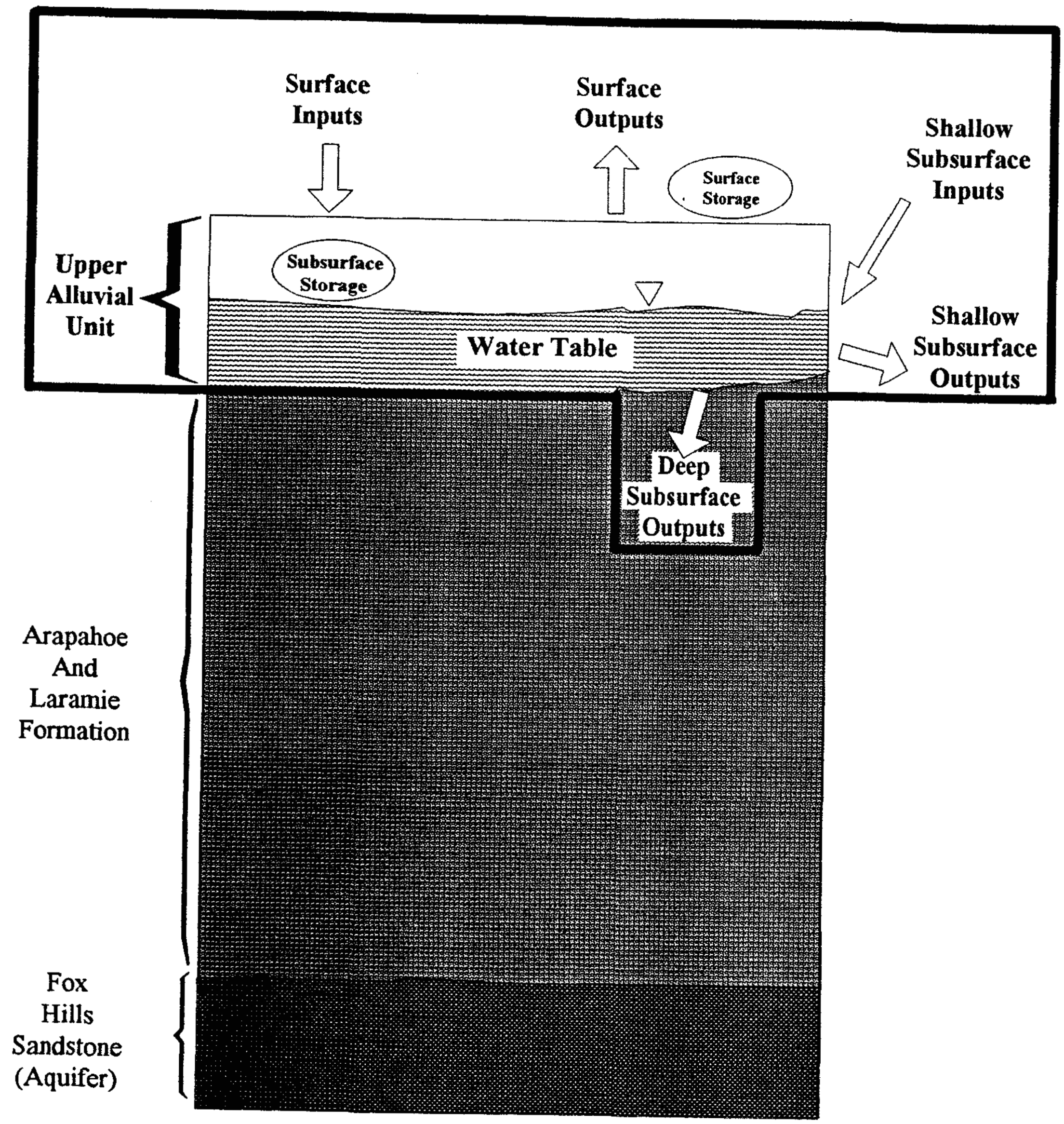

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Figure 2-8
SCHEMATIC OF WATER BALANCE BOUNDARY
(STUDY ELEMENTS ARE SHOWN IN BOLD)
SOLAR PONDS - OU4

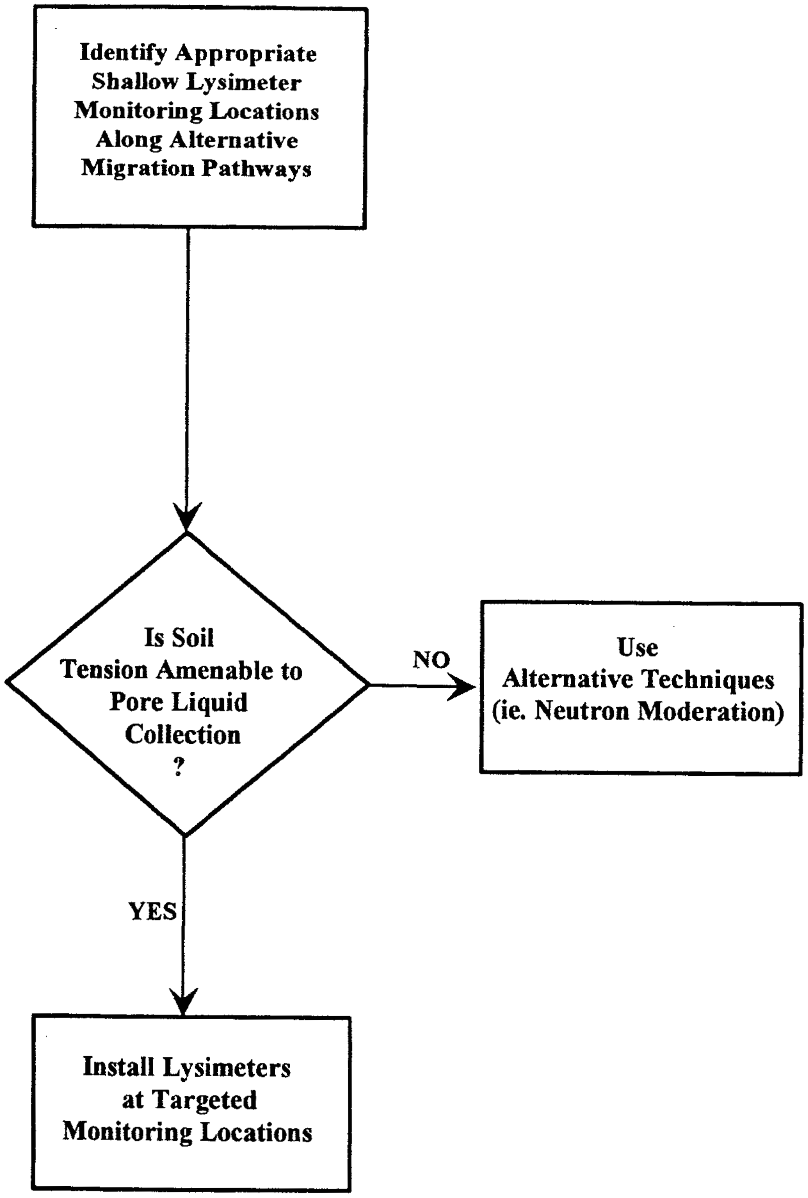

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Figure 2-9
PORE LIQUID SAMPLING
SOLAR PONDS - OU4

APPENDIX A

INITIAL DATA EVALUATION

APPENDIX A

A. Preparation of the vadose zone technical memorandum has required an ongoing evaluation of existing information regarding the OU4 area. The results of this initial data evaluation are summarized below. Descriptions of historical, hydrologic, and geologic evaluations are provided as a means of focusing the vadose zone and overall OU4 investigations. Although the existing information has been used to refine the proposed OU4 RI/RFI, the findings are considered preliminary in nature, and subject to later modification as additional data becomes available.

A.1 HISTORICAL DATA SUMMARY

A.1.1 <u>CHRONOLOGY</u>

This is a brief chronological listing of some of the data that is, or may be, pertinent to characterization of subsurface geologic, hydrogeologic, and chemical conditions in the Solar Pond area. An exhaustive evaluation of this data has not yet been performed. Figure A-1 shows the locations of the borings and wells identified to date.

1954 - A well was drilled off the northeast corner of the original clay-lined Solar Pond to a depth of approximately 16 feet. The well did not produce water. A large-diameter casing was installed, and apparently still exists.

1960 - Six wells were installed around the Solar Ponds, with emphasis on the Pond 207B area. Water quality data (pH, gross alpha activity, nitrate concentration, specific gravity, and depth to water) from these wells is available in monthly history/progress reports up to approximately 1970. Limited analyses of water from these wells also exist from 1970 to the early 1980s. Borehole logs for these wells are not known to exist. A natural gamma and a neutron (geophysical) log for hole 4-60 are available. These wells were abandoned in the recent well abandonment program.

1966 - Wells 2-66 and 3-66 were completed near the Solar Ponds in both alluvium and bedrock materials. Construction details and lithologic logs for these two holes are reportedly available, although copies have not yet been obtained.

1970 - A geological and subsoil investigation at the Solar Ponds was conducted to evaluate landslide potential north of the Solar Ponds. Ten boreholes were drilled to determine subsoil and groundwater conditions. Completion data and general lithologic logs are available on these wells.

1971 - Well 6-71 was completed due north of Pond 207A near the old perimeter road. The total depth of this well is approximately 61 feet, but no lithologic log is known to exist. This well was recently abandoned as part of the well abandonment program.

1974 - A Dow Chemical study was conducted that involved analysis of numerous soil samples for nitrate. The samples were obtained from fifty-six boreholes in three distinct areas north of the Solar Ponds. Most of these boreholes were terminated approximately 12 to 13 feet below the soil surface. Each of the three areas had borings 25 feet apart in rows. The rows varied in each area from 25 to 100 feet apart. Lithologic logs of these holes do not appear to have been recorded. Soils were analyzed for nitrate in this study.

1975 - An Engineering-Science report presented the results of a 31 hole boring program to investigate the presence of nitrate contamination near the Solar Ponds. The depth of these holes varied. They were located in a rough grid pattern over the northeast portion of the site. Limited cross-sectional data is presented in the report, but lithologic logs were not included in the report. Ground water was analyzed for nitrate in this study. Some of these cased boreholes still exist.

1986 - Installation of a RCRA-quality groundwater monitoring system began at the RFP. Data are reported in Section E (Volume VI & VII) of the RCRA Part B Permit Application of November 28, 1986. These data include lithologic logs, completion information, and aquifer tests. Approximately twenty-two of the wells (some well pairs) from the 1986 program were installed in the OU4 project area. Some brief conclusions from that study are presented below:

- Single hole pump tests indicated 1 x 10^{-3} cm/s hydraulic conductivity in the Rocky Flats Alluvium. None of the wells was in the OU4 area;

- The hydraulic conductivity was estimated to be 1 x 10^{-6} cm/s based on drawdown recovery tests, but no distinction was made between silty claystones and claystones;

- Packer or falling head tests were performed at various levels in approximately 18 wells at the RFP. Some of the wells (14-86, 15-86, 16-86, 17-86, 22-86, 25-86, 27-86, 32-86) are located within the OU4 area. The geometric mean hydraulic conductivity is 2 x 10^{-6} cm/s for the Arapahoe sandstone, 5 x 10^{-7} cm/s for weathered Arapahoe claystone, 1 x 10^{-7} cm/s for unweathered Arapahoe claystone, 7 x 10^{-5} cm/s for Rocky Flats Alluvium, and 2 x 10^{-2} cm/s for valley fill alluvium.

- It is believed that no chemical or physical tests were conducted on core soils from the 1986 wells; and

- Some of these holes were relogged due to questions regarding the accuracy of the logging.

1987 - Seventeen boreholes were installed in the Solar Pond area to investigate chemical conditions in the soils. These boreholes were not completed as wells. Borehole logs and chemical analyses of the soil samples are available. Some of these holes may have been relogged due to questions regarding the accuracy of the logging.

1988 - In the course of revising the RCRA closure plan for the Solar Ponds a fairly detailed evaluation of the site was conducted using all data available at that time except the well water analyses from the 1960s.

1989 - The subsurface investigation proposed in the 1988 Solar Pond Closure Plan and other characterization work were implemented in the Solar Pond area. This work included the completion of approximately 32 wells in the Solar Ponds area. Boreholes that were not completed as wells may also have been drilled. The sandstones that the 1988 program had been designed to specifically investigate were not found in any of the 1989 holes. This called into question the accuracy of the 1986 and 1987 borehole logs. Some core samples were then compared to the logs and significant errors were found. This prompted the overall site geologic characterization activities which involved relogging many of the previously completed holes.

1990 - A geotechnical investigation was conducted in the 881 Hillside french drain area (now OU1). This study is of pertinence to the Solar Pond area because it focused in part on the Arapahoe claystone which is thought to be similar site-wide. Both aquifer testing and geotechnical testing of the claystone materials were performed.

1991/1992 - As a part of the site-wide geological characterization, four boreholes were drilled near the OU4 area. Lithologic logs for these holes were developed with extreme detail. Soil chemical analyses were conducted on soil samples from the cores at these holes.

1991/1992 - As a part of the well abandonment and replacement program, most of the pre-1986 wells were abandoned. Some of the pre-1986 wells were replaced with new wells. Logs of the new wells were created. These activities were in conjunction with the site-wide geologic characterization study.

1992 - <u>Preliminary Investigation on Potential Leakage from the 207B Solar Evaporation Ponds</u>, July 13, 1992

This report details the activities of a brief investigation addressing whether the 207B Solar Ponds were currently leaking into the uppermost aquifer. This was done by sampling wells in the Solar Pond vicinity for a dye that was, and is, present in the 207B Solar Ponds. The wells that were sampled collected water in both the alluvium, and the silty claystones of the Arapahoe. Based on this study, no leakage was occurring from the 207B-series ponds.

1992 - Phase II RFI/RI Aquifer Test Report, Draft Final (for OU2), August 14, 1992

Pumping tests were performed at three sites within OU2 and yielded data on the Arapahoe sandstone and Rocky Flats Alluvium. The results of the tests indicated hydraulic conductivity of 4×10^{-4} cm/s for the Arapahoe sandstone and from 2×10^{-4} to 5×10^{-5} cm/s for the Rocky Flats Alluvium. Longitudinal dispersivity for the sandstone is reported as 0.19 ft and for the alluvium as 1.95 ft. Kinematic (effective) porosity is 12% for the sandstone and 0.3% for the alluvium.

The Arapahoe sandstone in the test site of OU2 exists as an unconfined aquifer. Saturated alluvium overlies the Arapahoe sandstone where the test was performed and they are hydraulically connected.

1992 - Phase II Geologic Characterization Data Acquisition Packer Injection Test Report, October 14, 1992

This report is one phase of the evaluation of geologic characteristics at the RFP. Packer injection testing of selected intervals in boreholes were performed to obtain estimates of the aquifer characteristics of the tested formations. Ten constant head injection tests and one falling head injection test were conducted at seven boreholes to isolate and test bedrock formation materials. Four of the boreholes were located approximately 4,000 feet north of OU4 in geologic materials similar to those found at OU4. The results of these tests indicate that hydraulic conductivities range from 1×10^{-6} to 4×10^{-8} cm/sec in bedrock materials. Overall geologic characterization data evaluation is continuing by EG&G personnel.

1992 - Draft Final, Phase III RFI/RI Report for OU1 [the 881 Hillside] October 1992.

This fourteen volume report contains considerable data (lithologic logs, many types of hydraulic conductivity tests, evaluation of contaminant movement, geotechnical soil analyses, chemical soil analyses, along with some modeling) on materials similar to those found in the OU4 area. The OU1 site is approximately 3,000 feet south of the OU4 site on the south slope of the same mesa on which the Solar Ponds are located.

A.1.2 ORIGINAL EARTHEN PONDS

The locations of Pond 2 and Pond 2-Auxiliary have been difficult to identify because the ponds no longer exist and because the area has changed a great deal since they did exist. Their locations, as presented in Figure A-2, have been identified based on a review of aerial and ground photographs and engineering drawings.

The three earthen ponds were constructed one at a time probably by RFP personnel or the on-site contractor and with no design drawings. The RFP personnel directly involved with their construction are no longer living, and, therefore, any interpretation is subject to error.

The original clay-lined pond, Pond 2, was constructed in October 1953. This pond was located in the area of the western half of current Solar Pond 207C. The method of construction included building dikes and lining the area with clay. The origin of the clay is not known, but was probably a local source. The elevation of the floor of the pond was approximately the same elevation as the surrounding area. The surface between the dikes and the original ground surface was subject to seeps along the north and east sides throughout it's active life. The seeps were repaired as needed with the addition of more clay. The corners of Pond 2 were identified from design Drawing 1-1454-207, 8/7/53. It appears from that drawing as though the southwest corner was cut off, although this is not supported by aerial photographs. Other drawings show the corner as a right angle. It is not thought to be of significance because the amount shown to be cut off in the drawing is negligible with respect to characterization and remediation efforts.

Pond 2-Auxiliary was originally constructed in September 1955. The dikes of the pond apparently were also built up from the ground surface so that the bottom of the pond was at the same elevation as the surrounding area. The dikes on this pond, especially the east side, were also subject to leakage at the ground surface. This pond was not lined when it was originally constructed, but was lined with clay in January 1957 shortly after Pond 207A was placed into service. It is suspected that the pond was slightly modified during lining. This issue is discussed further below.

The size and location of Pond 2-Auxiliary are identified on several engineering drawings (Drawing 2-4184 03/31/58; Drawing 2-7313-Z22, 07/17/61). There are no design drawings of the ponds identifying the relationship between Pond 2 and Pond 2-Auxiliary; however, the ponds are shown on design drawings of nearby structures. In these design drawings, Pond 2-Auxiliary is shown to be south of Pond 2, with its west berm located approximately in the center of the south berm of Pond 2 as shown in the top figure. The 1962 aerial photograph shows the west berm of Pond 2-Auxiliary to be aligned much closer to the east berm of Pond 2 as indicated in Figure A-2.

Utility drawings from 1958 (Drawing 2-4184) identify a below-ground process waste line at an angle from the valve vault west of Pond 2 toward the southeast. This line cuts across beneath the southwest corner of Pond 2-Auxiliary at angle of 54°30' from west. The alignment of this pipe is clearly visible on a July 1955 photograph as well as on an August 1962 photograph. By relocating Pond 2-Auxiliary to the east during construction, they avoided having to drive heavy equipment over the pipe during compaction of the clay liner and they were able to maintain the size of the pond. It is clear in the 1962 photograph that the pipe alignment just passes the outside of the southwest corner of Pond 2-Auxiliary.

The clay liner of Pond 2-Auxiliary was sampled and analyzed in 1963. The soil was found to be radioactively contaminated, and was disposed of in the East Trenches (OU2). The removal of Pond 2-Auxiliary was done in preparation for the construction of Building 779 in 1963/1964. An additional indicator of the pond location is provided by the relative location of Well 22-86. This well has been contaminated in the past, although it is upgradient of the current solar ponds. If Pond 2-Auxiliary were always in the location shown on the 1962 photograph, then the well would have been outside the pond berm. If Pond 2-Auxiliary were originally located further to the west as in the design drawings, then the well would have been inside the pond. The source of contamination in the well may not be due to the solar ponds regardless of the former locations of Pond 2-Auxiliary.

A.1.3 ORIGINAL EARTHEN POND SEEPAGE

In June 1954, Ed Ryan, a Rocky Flats engineer, noticed seepage on the hillside north of the original clay-lined pond, which was the only solar pond at the time. To investigate the seepage, he drilled a well at the northeast corner of the pond to a depth of 16 feet, but the well was dry. He also excavated a spring on the north slope of the mesa toward Walnut Creek using a dragline. The spring was sampled on a regular basis and analyzed for radioactivity and nitrate. The excavated spring and seepage area is apparent on an August 1954 aerial photograph. Ed Ryan postulated at the time that a large portion of the nitrate waste from the pond had been dispersed through seepage into the subsurface waters. He did not mention the well again so presumably is was always dry.

North of the center of Pond 207C is a 12-inch diameter perforated ⅛th-inch steel rivetted corrugated metal standpipe extending approximately 3 feet above the ground surface and has an overall depth of approximately 13 feet. This pipe, we believe, is Ed Ryan's 1954 well. This conclusion is supported by a September 1956 ground-level photograph of the original clay-lined pond in which this standpipe is visible, extending approximately 3 feet above the ground surface at the northeast corner of the pond. This pipe is visible in photographs from the 1960s as well, clearly showing its proximity to the clay-lined pond. Maury Maas, who operated the ponds since the late 1960s, stated that the pipe had been there as long as he was responsible for operation of the ponds.

Ed Ryan realized that the original pond was leaking because of the high nitrate concentration of the seepage north of the pond. He knew also that the north and east dikes of the pond seeped from time to time. He logically drilled a well at the northeast corner of the pond, but did not encounter ground water. The depth of the well was well below the bottom of the pond. In 1963, a pit was excavated to hold a propane tank (still there) immediately east of current solar pond 207C. The base of this pit is at an elevation of approximately 5969 feet, compared to the elevations of 5983 feet at the top of solar pond 207C berm and 5975 feet at the bottom of 207C. The base of this propane tank pit is below the base of solar pond 207C, and also below the base of the original clay-lined pond which was at an elevation of approximately 5978 feet based on the design drawings. The propane tank pit has never been reported to have seeped water, has always been dry in our personal experience since 1987, and was always dry in over 20 years of experience on the part of retired Rocky Flats personnel. Similarly, the cut for the propane tank does not have any phreatophytes present, also indicating that the propane tank cut is relatively free of moisture. This propane tank cut is located approximately 30 feet due west of the original clay-lined pond. This pit to the west was not subject to seepage and the well to the northeast of the pond has probably always been dry, as no records note water being encountered. This leads to the suspicion that there may have been a preferential pathway in the subsurface north of the pond, but not to the west or the northeast. This preferential pathway probably leads to the seep that Ed Ryan had noted in his reports, which is probably the same seep as we have identified in Section A.2 as the West Seep.

A.1.4 207A LINER HISTORY

When 207A was first complete in June 1956, inspection of the liner revealed separation of the felt and asphalt liner in some locations. The liner was repaired the following month.

In September 1958, aluminum paint was applied to the exposed surface to increase evaporation. It is not known how much of the surface was exposed at the time. No mention was found describing the removal or erosion of the aluminum paint. No photographs were found which provide details of the aluminum paint.

While the 207B ponds were being constructed in 1960/1961, 207A was believed to be leaking; however, due to the difficulties in completing the 207B ponds, liquid was transferred to 207A. After completion of the 207B ponds, both 207A and 207B were being used. In March 1962, during routine inspection, several breaks in the asphalt planking of 207A were discovered and liquid was transferred to 207B. Liquid from 207A was discovered to be leaking beneath the planking, seeping into the drainage tile, and being mixed with water in Pond A-1. By April 1963, relining of 207A began starting with the removal of salts and the cleaning of the exposed lining. Then in August 1963, the removal of the lining and the sand sub-grade began. In September 1963, the removal of the planking and the work for the new 207A redesign was completed. The lining and reforming of the new 207A began in October 1963. This redesigned pond was completed in November 1963.

According to the Monthly History Report of the Waste Disposal Co-Ordination Group for April 1968, all wastes were removed from 207A and it was dormant. However, an aerial photograph from April 10, 1968 does not show the pond to be empty. The emptying therefore must have taken place in the latter half of the month. An August 1969 aerial photograph shows the pond to be full.

To increase the evaporation rate from the ponds, a soaker hose was installed in May 1970 on the east berm of 207A. By August 1971, soaker hoses were installed around the entire perimeter of 207A. This allowed process waste to continuously drain down the exposed liner of the pond into the bottom of the pond.

Some close-up photographs of the solar ponds were taken in October 1976 which coincided with the development of plans for the new reverse osmosis plant. RFP Photograph negative numbers 21041, 21042, and 21043 were taken of the solar ponds. There is no description for each photo, but in some of the photos it is clear which pond is shown. Several photos clearly show that 207A is partially empty with most of the sides of the berms exposed. Salt encrustations show the former water line. The asphalt lining is sun-checked above and below the salt line. The fabric lining over the berm is sun-checked and torn in places. The salts on the side walls (liner) were surveyed in July 1980 and were found to have a count of 50,000 cpm.

A visual inspection of the solar ponds was performed as part of the development of the 1988 RCRA Closure Plan and it did not identify any cracks in the liner below the typical liquid level. In June 1988 aerial photograph indicates that 207A was empty. One transfer of liquid from the 207B ponds was made to 207A in March 1990 and incident precipitation has collected in 207A.

A.2 SOLAR PONDS SEEPAGE

For the purposes of this discussion, seeps are defined as any area in which soils appear to normally be moist or wet even though precipitation may not have recently occurred. Seepage areas may or may not be marked by the existence of phreatophytes, because nitrate concentrations in the seepage have been high enough to kill vegetation present. Seeps may or may not be marked with standing or flowing water. In discussions below where dimensions of a seep are given, the dimensions are based on the area in which the soils are moist. A schematic drawing of the seep locations is included in Figure A-3. Flowrates cannot be estimated, because they are not normally point sources of overland water flow.

Water quality data is available on the RFEDs system from surface water station monitoring seepage in the solar pond area. This data may include initial detailed suite of analytes, although once the seepage was characterized the number of analytes was commonly decreased. Listed below is a brief description of which of the surface water stations near the solar ponds may yield information directly related to seeps:

- SW-85 — This station is established on the seep (the "Building 779 Footing Drain Seep," as described later in this memo) immediately downhill from the Building 779 footing drain outfall.
- SW-89 — This station is established on old Sump 2.
- SW-90 — This station is established on the pump sump for old Trench 1.
- SW-105 — This station is established on the pump sump for old Trench 2.

- SW-102 This station was established immediately east of the old, riveted condensate tanks.
- SW-106 This station is established on old Sump 1.

A.2.1 WESTERN SEEP

This seep is marked in the field by cattails, moist soil, and some standing water. We believe that this is the seep that Edward S. Ryan made reference to in the 1950s as the "seep north of the solar ponds." This area is evident as a darkened, vegetated area on aerial photographs from the approximate period in which Ed Ryan was sampling the seep. The area also seems to have a narrow channel visible that would be consistent with a channel deepened and cleaned by a dragline. The western seep is located approximately due north of the eastern edge of solar pond 207C near the perimeter road. Specifically, the eastern edge of the seep is located north of light pole 43, approximately 5 to 10 feet west of an old erosion cut marked by large rocks that runs up the hillside. The northern edge is approximately 25 feet south of the wire fence just south of the PA perimeter road. Dimensions of the seep are approximately 30 feet by 40 feet.

There are currently no surface water monitoring stations established to sample moisture from this seep.

A.2.2 OLD TRENCH 2 SEEP

This seep is present immediately north and downhill of the sump for old Trench 2. The sump for Trench 2 is <u>not</u> Sump 2 near the solar ponds. The center of the seep is offset slightly to the east of the sump for Trench 2, and is approximately 25 feet in diameter.

The seep area is generally bare; apparently the vegetation has been burned out by high concentration of nitrate in the seepage. There appears to be a narrow band of vegetation between the Old Trench 2 Seep and the Large Hillside Seep to the east.

Current surface water monitoring station SW-105 is established at the pump sump for old Trench 2.

A.2.3 LARGE HILLSIDE SEEP

The Large Hillside Seep covers a large portion of the hillside north of solar ponds 207A and 207B, and is marked by a large area generally devoid of vegetation. The western edge of this seep is located approximately 5 to 10 feet east of the eastern edge of the Old Trench 2 Seep. The Large Hillside Seep extends down from a monitoring well access road, the historical perimeter road used prior to construction of the Protected Area, to the gravel backfill for the Interceptor Trench, which marks the northern extent of the currently operational Interceptor Trench Pump House system. The eastern edge is located approximately at monitoring well SEP2689BR.

The dimensions of the seep are approximately 100 feet in a north-south direction by 150 feet in an east-west direction.

The Large Hillside Seep area is generally bare; apparently the vegetation has been burned out by high concentration of nitrate in the seep water. It is possible that the moisture present is made up in part of water that flows out of Old Sump 2, which is located up the hillside from the seep. The "covered drainage tile" between solar ponds 207A and 207B empties into Sump 2, from which the water used to be returned to the solar ponds by a pump. The pump in Sump 2 is no longer operative, however, as a result, water flows out of the top of the sump, down the hillside, and into the soil immediately south of the monitoring well access road. The water then appears to reemerge from the ground on the north side of the monitoring well access road, creating the large seep and denuded area.

There is no surface water monitoring station established to sample the moisture form this seep.

A.2.4 OLD SUMP 2 SEEP

As described above, this seep could be considered an uphill, southern extension of the Large Hillside Seep described above. For the purposes of monitoring and characterization of the hillside, however, it seems reasonable to consider this a separate seep from the Large Hillside Seep, even if the two seeps are hydraulically connected. Unlike the other seeps described on this hillside, this seepage consists of more overland flow than moist soil, with the water moving in relatively definite drainage channels down the hillside. This seep begins at old Sump 2, and extends down the hillside to the monitoring well access road where the seepage appears to infiltrate into the soil. The seep is no more than five feet wide, and extends from old Sump 2 to the southern edge of the monitoring well access road. The total length of the old Sump 2 Seep is approximately 65 feet. Personal observations by the project team indicate that a considerable amount of water consistently flowed out of Sump 2 in 1988. Current flow is on the order of 20 to 25 percent of the fall of 1988 flow, although flow from this seep was never quantified.

Current surface water monitoring station SW-89 is established in the immediate vicinity of old Sump 2.

A.2.5 BUILDING 779 FOOTING DRAIN SEEP

This seep is located slightly downhill to the north of the outfall for the Building 779 footing drain, which consists of a cement-asbestos pipe half-buried in the ground. Although the footing drain outfall is dry, moisture present in the area could be carried in the drain pipe, infiltrating into soils upstream of the outfall, and then surfacing on the hillside. The Building 779 Footing Drain Seep is marked by greater plant growth than the surrounding area, and is roughly a triangle in shape, with the point of the triangle on the uphill side. The southern, uphill edge of the seep is located approximately at the SW85 monitoring station, with the seep extending

45 feet to the north. The seep is approximately 20 feet wide at the northern downhill edge of the seep.

Current surface water monitoring station SW-85 is located at the southern, uphill end of the seep.

A.3 SEEPAGE WATER QUALITY

Seepage water quality data were considered with known history of solar pond activities for the evaluation of the significance of nitrate concentrations in the hydrogeologic system near the solar ponds. Water Samples from collection sumps located north of the solar ponds were analyzed for nitrate concentration (as N) between 1975 and 1980. These data are presented in the 1988 Solar Pond Closure Plan.

As shown in Figure A-4, Sump 1 is located off the northeast corner of 207B-North. Sump 2 is located north of the area between 207A and 207B-North. Trench 3 was located northeast of 207B-North just upstream of the bifurcation of a gully that began north of the solar ponds and drained into North Walnut Creek. The sump is located on the northwest end of the trench, northeast of the east berm of 207B-North. Trench 6 was located along the original perimeter road and the sump was located at the northwest end, approximately due north of the west berm of 207C.

The nitrate concentrations from Sump 1, Sump 2, the Sump at Trench 3, and the sump at Trench 6 are plotted in Figure A-4 as concentration versus time for the duration of the data collection program. As can be seen, nitrate concentrations decrease abruptly in September 1975 for Sump 1, Sump 2, and Trench 3. Trench 6 data are unavailable prior to 1979. Nitrate concentrations prior to this change are approximately three to six times greater then subsequent measurements. Several conclusions were drawn from these data.

Included on the attached graph are pertinent solar pond activities that occurred during the sampling timeframe. There is an apparent relationship between the pond activities and the concentrations of nitrate in the water collected in the sumps. It is known that sometime between late April 1974 and early November 1974, 207B-North was emptied for repair. In early September 1975, there was a dramatic decrease in nitrate concentrations in all three sampling locations. This relationship was used to estimate a contaminant migration rate of nitrate through the surficial materials. The period between emptying the pond and the decrease in the nitrate concentrations was between 10 and 16 months. The distance from the center of 207B-North and the sumps varied between 200 and 550 feet, resulting in estimated nitrate migration velocities from 1.4×10^{-4} to 6.4×10^{-4} cm/sec. In October 1977, 207B-North was again emptied and there was again a significant decrease in the nitrate concentration of Sump 1 in May 1978. A nitrate migration velocity of 1.4×10^{-4} cm/sec is estimated. These nitrate migration velocities are comparable to the horizontal groundwater flow velocities calculated for the Rocky Flats Alluvium which ranged from 1×10^{-4} to 1×10^{-5} cm/sec (Part B Permit application, Section E, page 35). The flow velocities identified by the nitrate concentration data probably represent groundwater velocities because of the saturated condition of the soil with respect to nitrate.

The low and steady concentrations in Sump 1 from July 1978 to June 1980 can be directly related to the cleanout of the 207B ponds in general and specifically to the cleanout of 207B-North. This cleanout period occurred from approximately May 1976 through October 1977. The seven-month response time (between October 1977 and July 1978) in the nitrate concentration is consistent with the anticipated flow velocities.

The spatial relationships of Sump 1, Sump 2, and Trench 3 to the solar ponds is of significance. Sump 1 is located close to the northeast corner of 207B-North, and is therefore, most influenced by the 207B ponds. Nitrate concentrations in Sump 1 have a greater variability, than the other sampling stations as determined by the standard deviation of concentrations, indicating its sensitivity to the activities in 207B-North. Sump 2 is located north of the ponds between 207A and 207B-North, and is presumably influenced by the activities in both 207A and 207B-North. During the mid to late 1970s, 207A remained in routine use and was not emptied, repaired, and filled in the same manner that 207B-North was. The variability in the nitrate concentrations in Sump 2 indicates that it was not as sensitive to the activities in 207B-North as were the concentrations in Sump 1. In addition, the concentrations of nitrate in Sump 2 appear to be influenced by the seasons, increasing in the spring and decreasing in the winter. Trench 3 is located down the hill and further away from the solar ponds. Its greater distance makes it less sensitive to the discrete activities in the solar ponds. Moreover, Trench 3 was approximately 30 feet long and gravel-filled to the surface, collecting surface runoff as well as incident precipitation. These factors would tend to dampen variability in nitrate concentration as compared to the two sampling locations closer to the ponds. Despite the distance between Trench 3 and Sumps 1 and 2, however, there clearly is a similarity in the nitrate concentrations through time. The data imply that there is a hydraulic connection between Trench 3 and Sumps 1 and 2 and the solar ponds.

A.4 INTERCEPTOR TRENCH SYSTEM CONSTRUCTION DETAILS

One of the objectives of the vadose zone characterization activities is to determine the effectiveness of the Interceptor Trench System (ITS) in collecting the total flow of groundwater north of the solar ponds. The groundwater in this area is contaminated with some analytes, particularly nitrate, that are indicative of wastes placed in the solar ponds. If the ITS is not entirely effective in collecting all of the contaminated groundwater, then the ITS may need to be upgraded or additional remedial actions may need to be designed and implemented. A critical aspect in evaluating whether or not the ITS can collect all of the groundwater in the area north of the solar ponds is determining whether or not the collection pipes of the ITS are keyed into bedrock.

The ideal situation for collection of all the contaminated groundwater would be to have the ITS keyed into unweathered bedrock. However, according to Tim Lovseth of EG&G (personal communication, November 19, 1992) the weathered bedrock zone at the RFP varies from a depth of 20 to 50 feet below the top of bedrock. The ITS was constructed considerably more shallow than 20 to 50 feet into bedrock. Nonetheless, if the ITS is keyed into weathered bedrock, the majority of contaminated groundwater in the area may be collected by the system because the hydraulic conductivities of the bedrock materials are considerably less than the surficial materials. Packer tests were performed in 1986 at various levels in approximately 18 wells at the RFP. Some of these wells, including 14-86, 15,86, 16-86, 17-86, 22-86, 25-86, 27-86, and 32-86, are located within the OU4 area. The geometric mean for hydraulic conductivities in Arapahoe materials (bedrock materials) was 2×10^{-6} cm/s for the Arapahoe sandstone, 5×10^{-7} cm/s for weathered Arapahoe claystone, and 1×10^{-7} cm/s for unweathered Arapahoe claystone. The geometric means for hydraulic conductivities in Rocky Flats Alluvium was 7×10^{-5} cm/s and in valley fill alluvium was 2×10^{-2} cm/s. The greatest hydraulic conductivity for Arapahoe materials was found in the Arapahoe sandstone, a material which may not exist as a large continuous unit in the solar pond area. Even so, the difference in hydraulic conductivities between the surficial materials and the bedrock materials is more than an order of magnitude, making the surficial materials much more capable of conveying large volumes of water. Therefore, if the ITS is keyed into bedrock it may be quite effective in collecting the majority of the contaminated groundwater in the area, which appears to be moving in the surficial materials.

In order to evaluate whether or not the ITS was keyed into bedrock, the invert elevations on the as-built drawings for the ITS were compared with the draft top of bedrock elevation map prepared by Tim Lovseth of EG&G. The results of this comparison are provided in Table A-1. Information was also compiled from available utility, contour and isopach maps. Because information had to be manually transferred from one source to another to obtain the desired depths, and because some values used were linearly interpolated, the tabulated values should be considered approximations. The source drawings used for pipe invert elevations were 27550-033 for Pipes 1 through 6, 27550-040 for Pipes 6 through 18, and 27550-050 for Pipes 18 and 19. Elevations of the southern extension of the ITS were taken from drawings 26637-01 and 26637-02.

As can be seen from a brief review of the data, the pipes on the southeastern portions of the ITS are generally above the top of the bedrock; whereas the pipes on the northeastern portions and the southwestern portions of the ITS are typically below or near the top of bedrock. This relationship is illustrated in Figure A-5. The ITS should be relatively effective in collecting all of the contaminated groundwater from the surficial materials in the northeastern and southwestern areas of the ITS.

As an independent check on the above conclusion, we compared the locations where the ITS is keyed into bedrock with the occurrence of unsaturated surficial materials as noted in the Annual RCRA Groundwater Monitoring Report. The representation of the ITS presented in the Annual RCRA Groundwater Report had a number of inaccuracies which have been corrected in Figure A-6 based on as-built drawings.

The area of unsaturation in surficial materials agrees quite well with the areas in which the ITS is keyed into bedrock. The ITS is probably responsible for large areas of unsaturation that have been noted in past investigations, and the expected preferential pathways of migration in surficial/top of bedrock materials should largely be intercepted by the ITS.

As currently represented the area of unsaturation appears to coincide with an area in which the ITS is keyed into bedrock, with a downgradient "tail" area that remains unsaturated for some distance downgradient from the ITS. The precise boundary of the area of unsaturation is subject to interpretation, since not each boundary has a data control point near it. However, the smallest unsaturated area represented by four quarters of monitoring data was selected from the Annual RCRA Monitoring Report for use in this analysis.

A.5 DRAINAGE FEATURES

Review of historical aerial photographs from 1951, 1962, 1967, 1971, 1975 and other periods reveal the presence of surface drainage features which are now largely obliterated due to subsequent reworking of the hillside. Although land disturbance associated with construction of the ponds and perimeter roads has obscured their surface expression, subsurface hydrogeologic characteristics associated with these features are likely to continue to provide conduits for seepage and groundwater migration. The locations of these drainage features are identified in Figure A-7.

The drainages generally trend in a northeasterly direction from the solar ponds area, consistent with the orientation of other tributaries for Walnut Creek. One buried topographic drainage channel trends to the north from an area due north of the berm between Solar Ponds 207A and 207B. This channel is presented on photographs taken in 1967, 1971, and 1975, but is no longer apparent due to reworking of the soils during construction of the PA fence. Historical evidence indicates that this channel has been a preferential pathway for saturated flow based on the documentation of ground water seepage in a 1970 geologic and subsoil investigation. Old Trenches 1, 3, and 4 were constructed along the path of this drainage in the 1970s.

A second buried topographic drainage channel trends northeast from the northeast corner of Solar Pond 207B-North. This channel is presented on photographs taken in 1967, 1969, 1971, and 1975, but is no longer apparent due to the reworking of the soils during construction of the PA fence. Historical evidence indicates that this channel has also been a preferential pathway for saturated flow based on the documentation of ground water seepage in a 1970 geologic and subsoil investigation of the Solar Ponds. Old Trenches 2, 5A and 5B were constructed along the path of this drainage in the 1970s. Downslope of the PA, this drainage splits into two channels, possibly due to slumping of the hillside.

A third drainage trends to the east from the eastern edge of Pond 207B-Center through a portion of OU6, then trends downslope to the northeast.

A.6 GEOLOGIC CROSS SECTIONS

Preliminary geologic cross sections were prepared during development of the Phase I RI/RFI Work Plan from existing boring logs generated for the solar ponds area. These geologic cross sections are presented in Figures A-8 through A-12. Presented in these preliminary sections, and additional data of particular interest are the predominance of siltstones and claystones, and the discontinuous nature of isolated sandy units within the Arapahoe Formation beneath OU4. Information regarding depth to bedrock and bedrock type derived during the Phase I RI/RFI, will be used to refine these interpretive sections on an ongoing basis.

TABLE A-1

Comparison of Interceptor Trench System Construction Detail with Bedrock Elevation (Page 1 of 2)

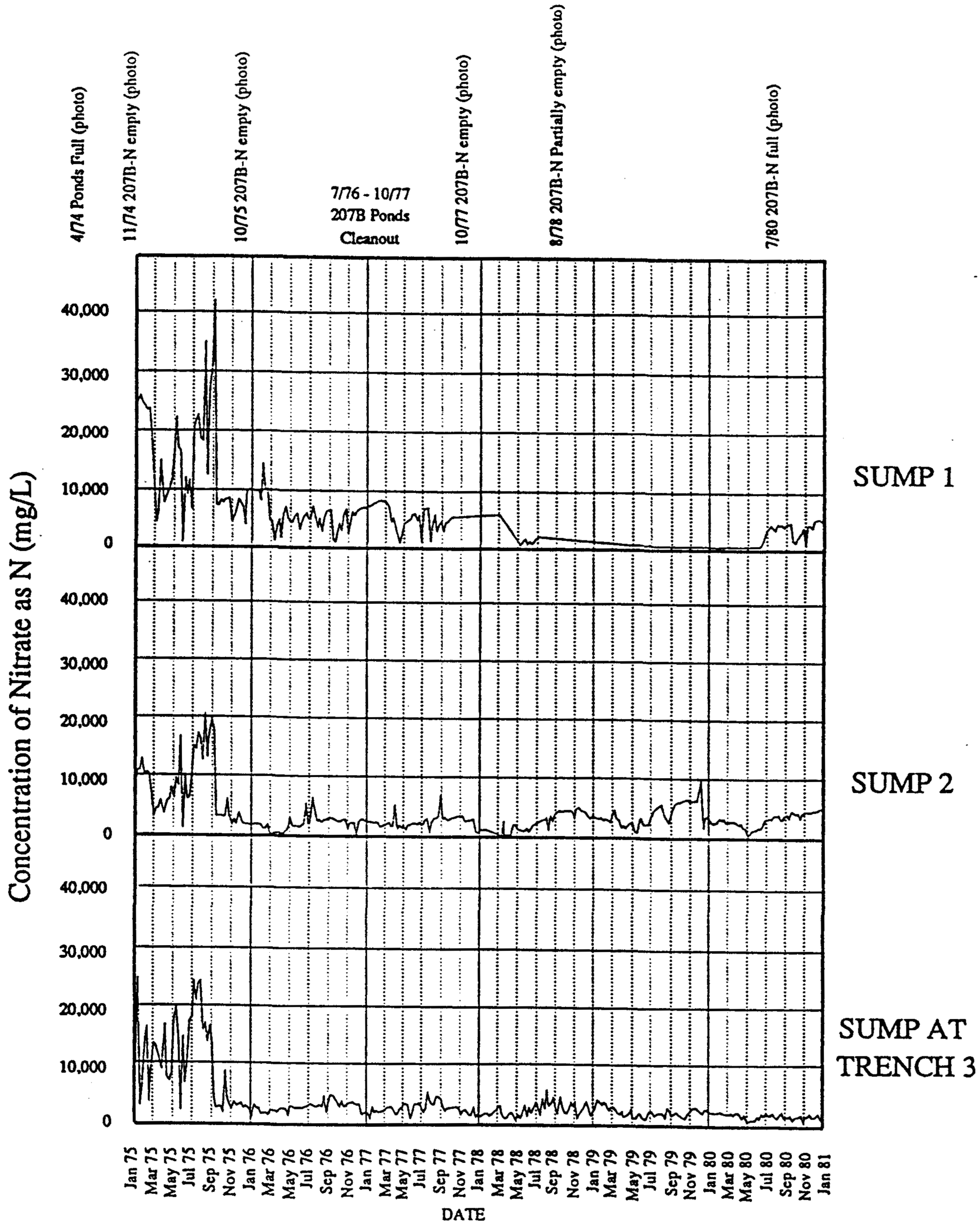
Pipe Number	Location of Pipe	Depth to Pipe (feet)	Depth to Bedrock (feet)	Bedrock Depth / Pipe Depth (feet)[1]
1	Northernmost Extent	13	19	6
	Southernmost Extent	13	15.5	2.5
	Center Dog Leg	20	10	-10
2	Northernmost Extent	12	13.5	1.5
	Southernmost Extent	6.5	17	10.5
	Center Dog Leg	10	15	5
3	Northernmost Extent	9.5	16.7	7.2
	Southernmost Extent	17	17	0
4	Northernmost Extent	15.6	21	5.4
	Southernmost Extent	14	17	3
5	Northernmost Extent	18.7	16.9	-1.8
	Southernmost Extent	3	21	18
6	Northernmost Extent	20	12	-8
	Southernmost Extent	3.5	14	10.5
7	Northernmost Extent	15	10	-5
	Southernmost Extent	4.5	10	5.5
8	Northernmost Extent	7	8	1
	Southernmost Extent	4	2	-2
9	Southernmost Extent	5.5	1	-4.5
10	Southernmost Extent	5	1	-4
11	Southernmost Extent	1	2	1

TABLE A-1

Comparison of Interceptor Trench System Construction Detail with Bedrock Elevation (Page 2 of 2)

Pipe Number	Location of Pipe	Depth to Pipe (feet)	Depth to Bedrock (feet)	Bedrock Depth / Pipe Depth (feet)[1]
12	Northernmost Extent	3	2	-1
	Southernmost Extent	0?	-4.5[2]	-4.5[3]
13	Northernmost Extent	16	25	9
	Southernmost Extent	4	-2[2]	-6[3]
14	Northernmost Extent	27	25	-2
	Southernmost Extent	3.5	-5[2]	-8.5[3]
15	Northernmost Extent	12.5	14	1.5
	Southernmost Extent	1.5	-5[2]	-6.5[3]
16	Northernmost Extent	5	13	8
	Southernmost Extent	2	-1.5[2]	-3.5[3]
17	Northernmost Extent	8.5	12	3.5
	Southernmost Extent	3.5	2	-1.5
18	Northernmost Extent	8	14	6
	Southernmost Extent	2	3	1
19	Northernmost Extent	7	13	6
	Southernmost Extent	6	3	-3
Southern Extension	East End	8	22	14
	Center (Manhole)	5.7	-5[2]	-10.7[3]
	West End of French Drain	2.6	4	1.4

[1] Positive number indicates bedrock is deeper than pipe; negative number indicates pipe penetrates bedrock.
[2] Negative number indicates bedrock above ground surface based on available data.
[3] Results questionable, requiring additional evaluation.



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PREPARED FOR
U.S. DEPARTMENT OF ENERGY
ROCKY FLATS PLANT
GOLDEN, COLORADO

FIGURE A-4
NITRATE CONCENTRATION
IN SEEPAGE
SOLAR PONDS OU-4

APPENDIX B

VADOSE ZONE SOPs

SOP VZ.1

PROCEDURE FOR USING THE DOUBLE-RING INFILTROMETER

PROCEDURE FOR USING THE DOUBLE-RING INFILTROMETER

Forms

PROCEDURE FOR USING THE DOUBLE-RING INFILTROMETER

2.0 PURPOSE AND SCOPE

This Standard Operating Procedure (SOP) describes the materials and procedures that will be used at the Rocky Flats Plant (RFP) to install and operate Double-Ring Infiltrometers for determination of infiltration rates in unsaturated soils. All activities will be conducted in accordance with the Health & Safety Plan (HSP) that will be developed for these activities.

3.0 QUALIFICATIONS

Personnel installing and performing Double-Ring Infiltrometer tests will be geologists, hydrologists, hydrogeologists, engineers, soil scientists, or field technicians with an appropriate amount of applicable field experience or on-the-job training under supervision of a qualified person. All personnel performing this procedure are required to have 40-hour OSHA classroom training which meets the Department of Labor regulation 29-CFR 1910.120(e)(3)(i).

4.0 REFERENCES

The following is a list of references reviewed prior to the writing of this procedure.

4.1 SOURCE REFERENCES

Burgy, R. H., and J. N. Luthin, 1956. A Test of the Single and Double-Ring types of Infiltrometers. Transactions American Geophysical Union, Vol. 37, pp. 189-191.

Swartzendruber, Dale, and T. C. Olson, 1961b. Model Study of the Double-Ring Infiltrometer as affected by Depth of Wetting Front and Particle Size. Soil Science, Vol. 100, pp. 44-51.

ASTM Standard D3385-88: Standard Test Method for Infiltration Rate of Soils in the Field using Double-Ring Infiltrometers.

4.2 INTERNAL REFERENCES

Related SOP's cross-referenced by this SOP are as follows:

- SOP FO.3 General Equipment Decontamination

- SOP GT.7 Logging and Sampling of Test Pits, Trenches, and Construction Activities.

5.0 INSTALLATION OF DOUBLE-RING INFILTROMETERS

The Double-Ring Infiltrometer consists of two cylinders (square cross-sections may also be employed) which are driven into the ground. The installed rings are partially filled with water or other liquid, where liquid levels are maintained over time as infiltration into the underlying soils proceeds. Recorded parameters are used to calculate the infiltration rate of liquid into the target soils.

5.1 MATERIALS AND EQUIPMENT

- Infiltration rings or squares (dimensions may vary from one application to another).
- Driving caps or disks
- Driving equipment (hammers and/or hydraulic jacks)
- Depth measurement device
- Shovel
- Liquid containers (drums or buckets)
- Test soil cover material
- Calibrated liquid head tanks
- Timepiece

- Level (carpenters or bullseye)
- Thermometer
- Field notebook with appropriate forms
- Decon Equipment
- Distilled Water
- Liquinox

5.2 PROCEDURES

The following procedures describe the installation of the Double-Ring Infiltrometer apparatus. The procedures outlined are designed to ensure an effective seal between the infiltrometer rings and the native soils while minimizing disturbance.

- The test site should be nearly level, or a level surface should be prepared.

- If testing at depth is preferred, a pit of suitable dimensions shall be excavated (SOP GT.7: Logging and Sampling of Test Pits, Trenches, and Construction Excavations)

- Decontaminate all equipment prior to installation (see SOP FO.3 General Equipment Decontamination)

- Leave the exposed soil in its natural condition and remove only woody stems, rocks, or other items that may obstruct the lower rings and impede effective driving.

- In soft soils, push the outer ring into the soils to the desired depth. In harder soils, installation may require hammers with driving disks and/or jacks (refer to ASTM D3385 Standard Test Method for Infiltration Rate of Soils in the Field using Double-Ring Infiltrometers).

- After driving the outer ring to the selected depth, center and drive the inner ring inside of the outer ring using the same procedure.

- Using a level, ensure that inner and outer rings are each installed in a horizontal orientation. Using a measuring tape, measure and record the depth of installation.
- Ensure that no visible macropores exist between the cylinders and native soil. If macropores are noted to exist, tamp native soils surrounding the walls of the inner and outer rings.

- Connect the water reservoir(s) and calibrated constant head tanks to the infiltrometer device (see Figure 2 of ASTM Standard D3385 Standard Test Method for Infiltration Rate of Soils in the Field using Double-Ring Infiltrometers).

- Record appropriate field parameters listed in Form VZA.

6.0 OPERATION OF DOUBLE-RING INFILTROMETER

The following generalized description is to be employed in the field for effective operation of the Double-Ring Infiltrometer device for measuring infiltration rates in soil.

- Select the appropriate liquid head on the reservoirs on the basis of the permeability of the soil, where higher heads are required in lower permeability soils. Record established head on Form VZA.

- Cover the exposed test soil surface with a cover material made of burlap or other material to prevent erosion within the rings during addition of the water supply.

- Add liquid to fill both rings to the same desired height. Do not record this initial volume of water added.

- Record temperature of test liquid on Form VZA.

- Start liquid flow from the calibrated head tanks as needed to replenish infiltrated liquid.

- Determine and record the volume of liquid that is added to the initial volume to maintain a constant head in the inner ring and annular space during each time interval by measuring the change in elevation of the liquid level in the calibrated head tanks (use Form VZA).

- Place a cover over the infiltrometer assembly during testing to minimize evaporation of liquid.

- For average soils, record the volume of liquid added at approximate intervals of 15 minutes for the first hour, 30 minutes for the second hour, and 60 minutes during the remainder of a period of a least 6 hours, or until a relatively constant infiltration rate is arrived at. Note: these are suggested recording intervals and may vary significantly in the field depending on soil textures.

7.0 DECONTAMINATION

All equipment and materials that come into contact with native soils will be decontaminated prior to and following each Double-Ring Infiltrometer test at each location according to SOP FO-3 General Equipment Decontamination.

8.0 DOCUMENTATION

All field records will be entered on Form VZA prior to and during testing. Final reporting will be entered onto Form VZB following completion of infiltration testing at each site. Field observations and data will be recorded with black waterproof (permanent) ink onto the field data forms.

Trial Number		Date	Time hr:min	Elapsed Time △/(Total) min	Flow Readings: Inner Ring Reading CM	Flow Readings: Inner Ring Flow CM^3	Flow Readings: Annular Space Reading CM	Flow Readings: Annular Space Flow CM^3	Liquid Temp. C°	Incr. Infilt. Rate Inner CM/h	Incr. Infilt. Rate Annular CM/h	Ground Temp. = ______ @depth of ______ ______ Remarks: Weather conditions, etc.
1	S											
	E											
2	S											
	E											
3	S											
	E											
4	S											
	E											
5	S											
	E											
6	S											
	E											
7	S											
	E											
8	S											
	E											
9	S											
	E											
10	S											
	E											

Project Identification: ______
Test Location: ______
Liquid Used: ______ pH: ______
Tested By: ______
Depth to Water Table: ______

Constants:	Area (CM^2)	Depth of Liquid (CM)	Liquid No.	Containers Vol/△ H (CM^2/CM)
Inner Ring:				
Annular Space:				

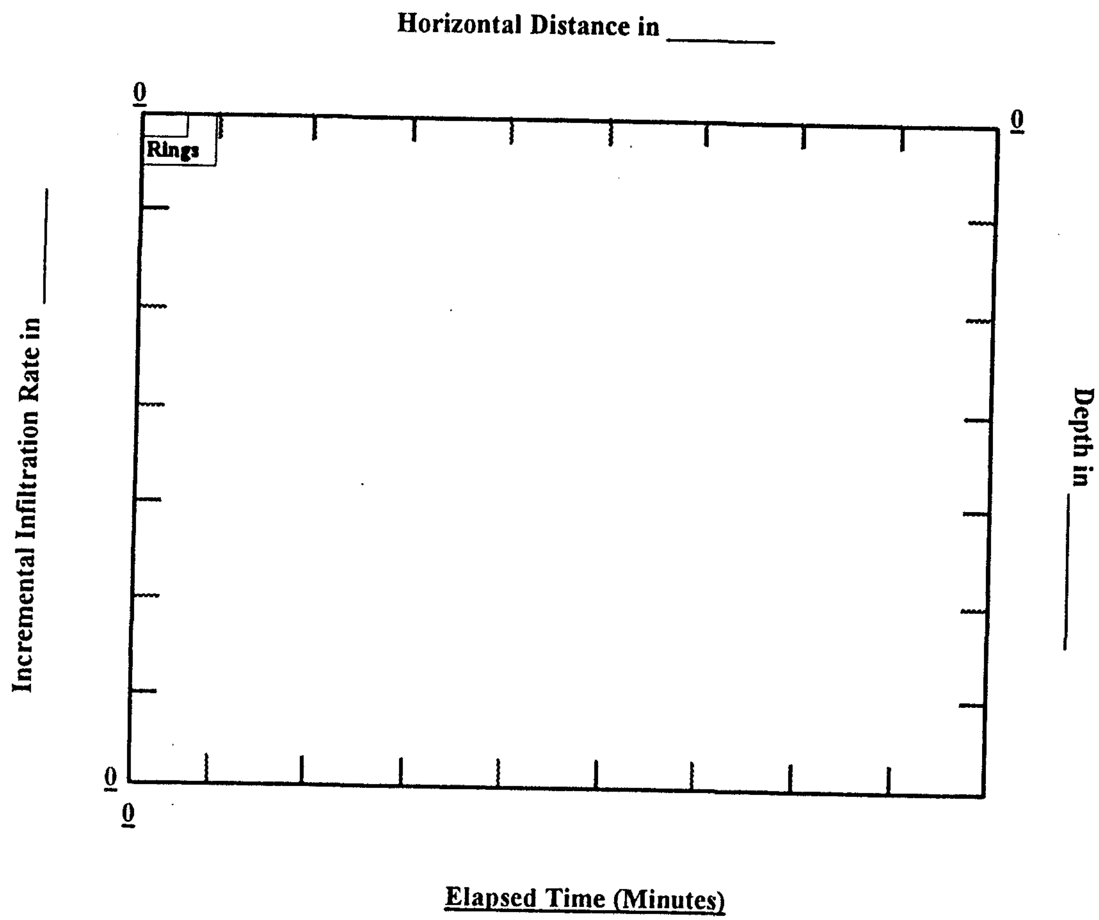
Liquid Level Maintained using: ☐ Flow Value; ☐ Float Value; ______

(____) Penetration of Rings: Inner: ______ (____); Outer: ______

Prepared For
U.S. Department of Energy
Rocky Flats Plant, Golden, Colorado

Form VZA
Data Form for Infiltrometer Test with Sample Data

Project Identification: ______ Prepared By: ______ Date of Test : ______ Finish: ______
Project Location: ______ Remarks: ______
Liquid Used: ______ pH: ______;Ave. Temp: ____ ± ____



Soil Profile Description

Prepared For
U.S. Department of Energy
Rocky Flats Plant, Golden, Colorado

Form VZB:
Report Form for Infiltrometer Test with Sample Data

SOP VZ.2

PROCEDURE FOR USING THE GUELPH PERMEAMETER

PROCEDURE FOR USING THE GUELPH PERMEAMETER

Figures/Forms

GUELPH PERMEAMETER

2.0 PURPOSE AND SCOPE

The purpose of this standard operation procedure (SOP) is to provide the technical guidance and methods that will be used at the Rocky Flats Plant (RFP) for the installation and operation of the Guelph Permeameter for hydraulic conductivity and matric flux potential determination. All activities associated with this SOP will be conducted in accordance with the Health and Safety Plan (HSP) that will be developed for these activities.

3.0 QUALIFICATIONS

Personnel installing and operating equipment will be geologists, hydrologists, soil scientists, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

Green, R. E., L. R. Anuja, and S. K. Chong, 1986. Hydraulic Conductivity, Diffusivity, and Sorptivity of Unsaturated Soils: Field Methods. In: Methods of Soils Analysis, Pt.1. C. A. Black (ed.) Agronomy no. 9, pp. 771-798. American Society of Agronomy. Madison, Wis.

Reynolds, W. D., and D. E. Elrick, 1985. Measurement of Field-Saturated Hydraulic Conductivity, Sorptivity, and the Conductivity-Pressure Head Relationship using the Guelph Permeameter. Proc. NWWA Conf. on Char. and Monitoring of the Vadose (Unsat.) Zone. Denver, Col., November, 1985.

4.2 INTERNAL REFERENCES

- SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations.

- SOP FO.3, General Equipment Decontamination.

5.0 INSTALLATION OF THE GUELPH PERMEAMETER

This section provides the step by step procedures for the field preparation and installation of the Guelph Permeameter instrument.

5.1 MATERIALS AND EQUIPMENT

The following list of materials and equipment associated with the Guelph Permeameter with the exception of water are provided as a complete field-ready kit. The kit is separated into seven basic sections as listed below:

- Tripod assembly
- Support tube and lower air tube fittings
- Reservoir assembly
- Well head scale and upper air tube fittings
- Accessory installation and operation tools
- A complete parts list for the Guelph Permeameter kit is presented in the Guelph Permeameter 2800 KI Operating Instructions.
- Decontamination Equipment

If a field kit is not used, some of the procedures listed below may be altered to be applicable to the actual equipment used. In addition to those listed, the following items must also be made available:

- Clean water supply
- Field notebook with Forms VZ.2-1 and VZ.2-2

5.2 PROCEDURES

The goal of effective permeameter installation is to cause minimal disturbance to native soils while permitting the measurement of hydraulic conductivity and matric flux potential in targeted soil using the Guelph Permeameter. The following steps for use of the Guelph Permeameter in the field include the completion of a soil excavation at the intended measurement site(s), preparation of well hole(s), assembly of the permeameter, filling the reservoirs with water, and placing and securing the permeameter into the well hole(s), measuring hydraulic conductivity. These steps will be completed as described below.

5.2.1 INSTALLATION

- Well hole preparations will be completed using the two soil augers provided in the Guelph Permeameter kit. The soil cutting auger will be advanced to the pre-selected measurement depth(s), typically 12-15 inches below grade, and the cuttings will be disposed of according to EG&G EMD procedures.

- The pilot hole will next be reamed out using the sizing auger to clean out the well hole and achieve uniform geometry.

- The appropriately sized well hole will then be scraped with the well preparation brush by pushing the brush evenly into the excavated hole to the bottom, and pulling the brush back out. Repeat this process no more than two to three times as over-reaming the hole can create excessive void space.

- The water-filled, assembled permeameter will be centered over the well hole and the water outlet tip slowly lowered until it rests on the well bottom. (See Operator's Manual for detailed assembly and reservoir filling procedures).

- Final installation encompasses centering and stabilizing the permeameter assembly (Figure SOP VZ.2-1). For wells deeper than 15-inches, the tripod bushing alone provides the functions of centering and stabilizing the permeameter (Figure SOP VZ.2-2).

6.0 OPERATION OF GUELPH PERMEAMETER

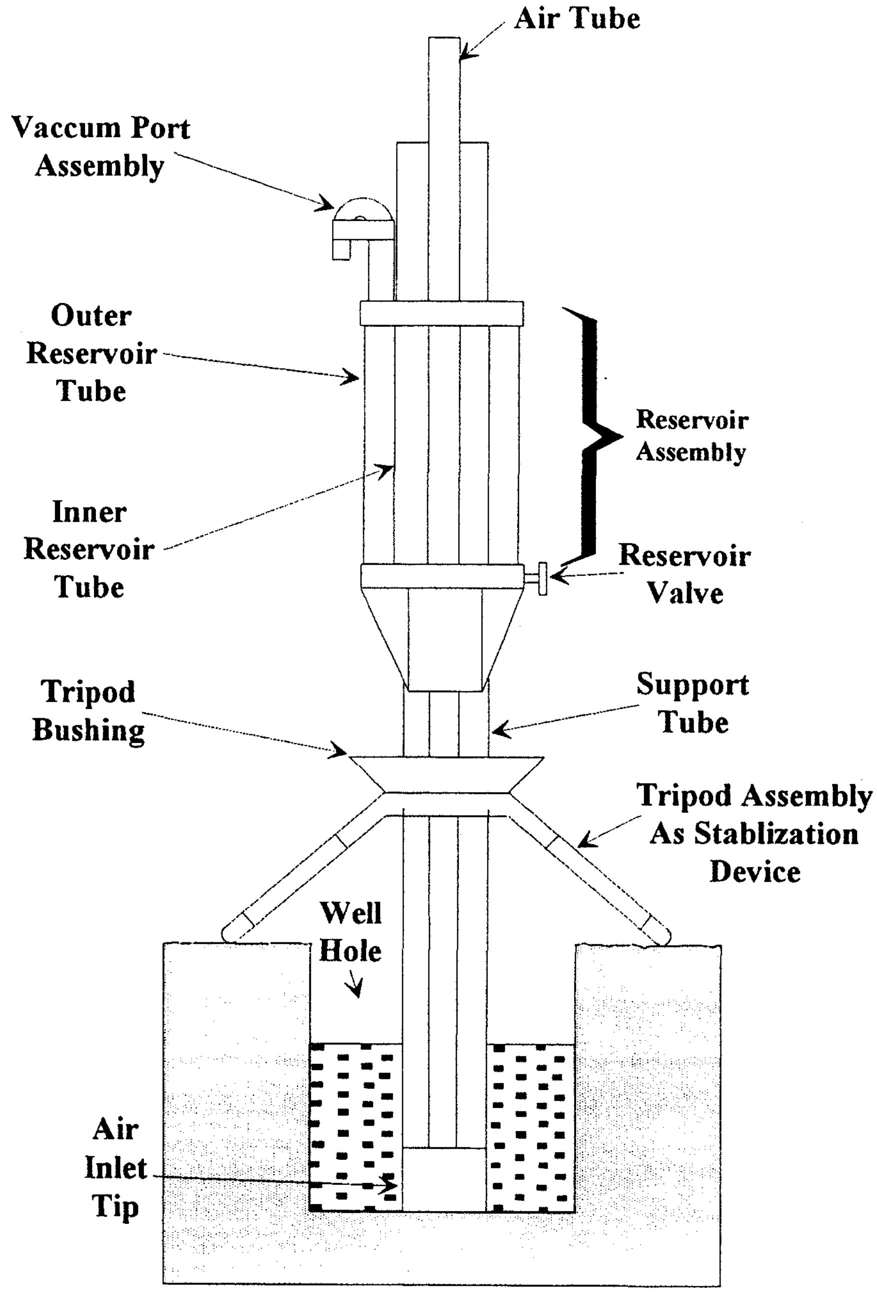
After the permeameter has been assembled, filled, placed and secured in the prepared well hole, the following procedures will be followed for making measurements at two well head heights for hydraulic conductivity and matric flux potential determination.

- Verify that the reservoirs are connected, the water fill plug is in place, the well height indicator and well head scale are seated against the reservoir cap, and the vacuum tube is clamped shut.

- Establish the first well head height by slowly raising the air inlet tube.

- Observe and note the rate of water level decline in the selected reservoir (use Form VZ.2-2). As a standardized procedure, readings at 2-minute intervals are suggested.

- Continue noting readings until three consecutive readings indicate stable, steady-state conditions of well flow. (Note: For steady-state conditions to prevail in different soil types, the required time interval may exceed the suggested two-minute time interval).



Prepared For
U.S. Department of Energy
Rocky Flats Plant, Golden, Colorado

Figure SOP VZ.2-1
Permeameter Installation
Detail For Shallow
(<15 Inches) Well Holes

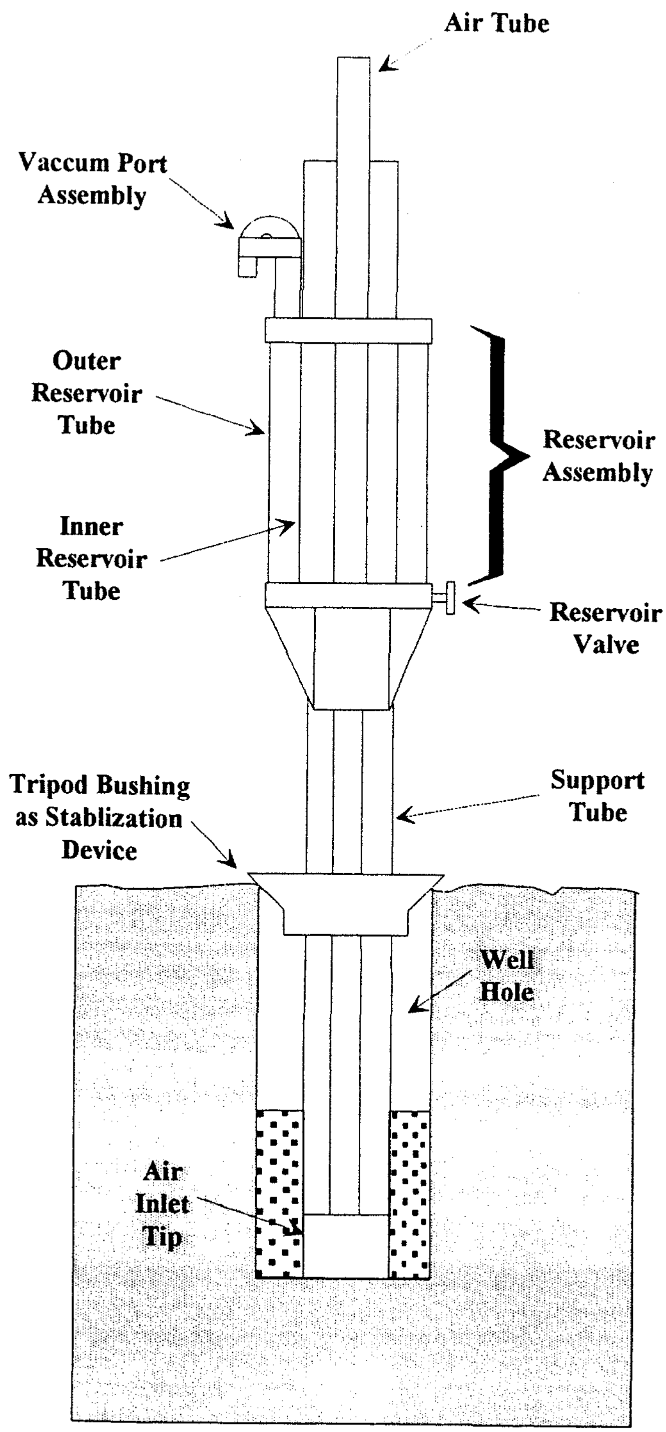


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Figure SOP VZ.2-2
Permeameter Installtion
Detail For Deep (>15 Inches)
Well Holes

- Following successful measurements at steady-state conditions for the first well head height, repeat procedures at a second well head height (second well head height will be larger than the first well head height).

- Perform calculations of hydraulic conductivity and matric flux potential using completed Form VZ.2-2. Refer to Operator's Manual for further details and trouble-shooting.

7.0 DECONTAMINATION

Well hole augers will be decontaminated prior to excavating each well hole and at the conclusion of the operations. Additionally, components of the Guelph Permeameter which contact contaminated soils will be decontaminated prior to use and following the conclusion of the operations.

Specific decontamination procedures are described in SOP FO.3, General Equipment Decontamination.

8.0 DOCUMENTATION

All field information required by this SOP will be documented in Forms VZ.2-1 and VZ.2-2. Form VZ.2-1 will be used to record data gathered during excavation of the well hole(s) and describe soil and site conditions. Form VZ.2-2 will be completed during actual measurements of the hydraulic conductivity using the Guelph Permeameter. Field observations and data will be recorded with black waterproof (permanent) ink on the field data forms.

Date ______________ Investigator ______________________________

Site Location ______________________________

Dominant Soil Type(s) ______________________________

Site Map:

Soil Profile Description (horizon depth, texture, structure, color, etc.):

Depth	Description

Presence of special soil conditions (mottling, water table depth, hardpan, induration, compacted layers, etc.):

____

____

____

____

____

Comments and Notes (topography, slope, vegetation, etc.):

____

____

____

____

GP FIELD DATA SHEET

FORM VZ.2-2 : STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS

Date ________________ Investigator __________________

Reservoir Constants: (See Label on Permeamter)

Combined Reservoirs X		cm^2
Inner Reservoir	Y	cm^2

☐	CHECK RESERVOIR USED
☐	

Depth of Well Hole_____

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R, (CM/MIN)

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R, (CM/MIN)

CALCULATIONS

$\overline{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\overline{R}_1 = (\underset{R_1}{\_\_\_\_\_\_})/60 =$ ______ cm/sec

For the 2nd Set of Readings $\overline{R}_2 = (\underset{R_1}{\_\_\_\_\_\_})/60 =$ ______ cm/sec

K_{fs} = [(.0041)(______)(______)] - [(.0054)(______)(______)] = ______cm/sec

FIELD SATURATED HYDRAULIC CONDUCTIVITY — RESERVOIR CONSTANT — $\overline{R}_2$-STEADY STATE RATE OF FLOW — RESERVOIR CONSTANT — $\overline{R}_1$-STEADY STATE RATE OF FLOW

ϕ_m = [(.0572)(______)(______)] - [(.0237)(______)(______)] = ______cm^2sec

MATRIC FLUX POTENTIAL — RESERVOIR CONSTANT — $\overline{R}_1$-STEADY STATE RATE OF FLOW — RESERVOIR CONSTANT — $\overline{R}_2$-STEADY STATE RATE OF FLOW

α = $(\underset{K_{fs}}{\_\_\_\_\_\_})/(\underset{\phi_m}{\_\_\_\_\_\_})$ = ______ cm^{-1}

ALPHA PARAMETER

$\Delta\Theta$ = (______________) - (__________) = ______ cm^3/cm^3

DELTA THETA — Θ_{fs}, FIELD SATURATED WATER CONTENT OF SOIL, IN CM/CM — Θ_i, AMBIENT WATER CONTENT OF SOIL, IN CM/CM

ESTIMATED		CHECK ONE
MEASURED		

$S = \sqrt{2\,(\underset{\Delta\Theta}{\_\_\_\_\_\_})\,(\underset{\phi m}{\_\_\_\_\_\_})}$ = __________ cm $sec^{-1/2}$

SORPTIVITY

S0P VZ.3

PROCEDURES FOR THE INSTALLATION OF EQUIPMENT AND MEASUREMENT OF MATRIC POTENTIAL IN THE VADOSE ZONE USING TENSIOMETERS

A STANDARD OPERATING PROCEDURE FOR INSTALLATION AND USE OF TENSIOMETERS IS CURRENTLY UNDER DEVELOPMENT BY EG&G. MODIFICATIONS SPECIFIC TO THE OU4 VADOSE ZONE INVESTIGATION WILL BE INCORPORATED INTO THESE DRAFT STANDARD OPERATING PROCEDURES, OR WILL BE IMPLEMENTED AS DOCUMENT CHANGE NOTICES

SOP VZ.4

PROCEDURE FOR DIELECTRIC WATER CONTENT MEASUREMENT

PROCEDURE FOR DIELECTRIC WATER CONTENT MEASUREMENT

Figures

DIELECTRIC WATER CONTENT MEASUREMENT

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to install, calibrate, and perform measurements of in-situ water contents of earth materials. Two measurement techniques are specified in this SOP; Time Domain Reflectometry, and Frequency Domain Capacitance. Each technique utilizes equipment that will be installed within augered boreholes or trenches (see SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations, for excavation, sampling, backfilling, and decontamination procedures). All activities will be conducted in accordance with the Health and Safety Plan (HSP) that will be developed for these activities.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel installing equipment and performing measurements will be geologists, hydrologists, soil scientists, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

Fletcher, J.E., 1939. A dielectric method for determining soil moisture. Soil Sci. Society of Amer. Proceedings. vol 4, pp. 84-88.

Topp, G. C., 1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. Water Resources. vol. 16, pp. 547-582.

4.2 INTERNAL REFERENCES

Related SOP's cross-referenced by this SOP are as follows:

- SOP GT.20, Rev. 2 Procedures for Soil Interstitial Water Sampling and Sampler Installation.

- SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Activities.

- SOP FO.3, General Equipment Decontamination

- SOP FO.4, Heavy Equipment Decontamination

5.0 INSTALLATION OF DIELECTRIC WATER CONTENT MEASUREMENT SYSTEMS

5.1 MATERIALS AND EQUIPMENT

5.1.1 Time Domain Reflectometry (TDR)

- Wave Guide(s)
- Wave Guide Connectors(s)
- Insertion Tool
- Hammer
- Coaxial Cable(s)
- Measuring Tape (25 feet length or greater)
- TDR Processor (Trase System 1 or equivalent)
- Battery Charger
- Field Notebook/Operators Manual

5.1.2 Frequency Domain Capacity (FDC)

- FDC Control Unit (Troxler Sentry 200 or equivalent)
- FDC Probes(s)
- Pilot Hole Auger/Insertion Tool or equivalent
- Core Removal Tool
- Charger/Adapter
- Measuring Tape (25 feet length or greater)
- Field Notebook Operators Manual

5.2 PROCEDURES

5.2.1 TDR Installation

The goal of TDR wave guide installation is to minimally disturb the native soils, and to ensure good hydraulic contact and minimize the existence of "air gaps" between the native soil and wave guide elements. The following steps will be performed to correctly install the TDR wave guide probes (see SOP GT.20, Rev. 2, Procedures for Soil Interstitial Water Sampling and Sampler Installation).

- Excavate a soil pit or advance a soil boring to the desired depth of the measurement interval(s). Record all depth measurements in the field notebook.

- Complete Form SOP GT.7 to describe soil profile at each installation.

- Select the appropriate length of wave guide(s) for installation (refer to Operators Manual, pp. 35).

- Insert the wave guides into the native soils such that the guides completely penetrate the desired soil measurement interval. Use the installation tool/alignment block when inserting the surface-mounted portable probe.

- When making a measurement using pre-installed wave guides, align the wave guide connector over the ends of the installed wave guides, press down until the guides are fully seated in the wave guide sockets, and tighten the clamping knob. When using buriable wave guides, the preselected length of coaxial cable shall be sufficient to extend upwards to an accessible measurement location for each installation.

- When using buriable wave guides, backfill the installation with 5% Bentonite/95% Portland Cement Mixture, packing the mixture firmly about the wave guide probe. Care should be exercised during mixture preparation to avoid the use of excess water.

5.2.2 FDC Installation

The goal of FDC probe installation is to minimally disturb the native soils and to ensure good hydraulic contact and minimize the existence of air gaps between the probe and the native soil. The following steps will be performed to correctly install the FDC probes.

- Excavate a soil pit or advance a soil boring to the desired depth of the measurement interval(s).

- Using a hand auger tool with dimensions slightly larger than the outside diameter of the probe, auger a pilot hole approximately 4 inches into the desired measurement zone. Record all depth measurements in the field notebook.

- Remove loose dirt from auger hole prior to inserting probe.

- Connect to probe and insert the probe into the augured pilot hole. Note: The preselected length of cable at each location shall be sufficient to extend upwards to an accessible measurement location for each installation.

- Measure depth of installed probe and record in field notebook.

- Backfill installation with 5% Bentonite/95% Portland Cement Mixture, packing the soil mixture firmly on top of the probe and around the cable. Care should be exercised during mixture preparation to avoid the use of excess water.

6.0 WATER CONTENT DATA ACQUISITION

The following steps outline the procedures to perform water content measurements of earth materials using TDR and FDC techniques.

6.1 TDR

- Turn TDR processor unit on and update internal clock and calendar as needed.
- Push **ON ENTER** then **NEXT SCREEN** until "measure screen" appears.
- Connect the wave guide cable to the connector port.
- Push the **MEASURE** button and record the moisture content.
- Take 3 readings with each probe and ensure all are within 1%; if the readings are not within 1%, see the Operator's Manual.
- Save all field data as needed using the on-board data logger and periodically download saved data onto a personal computer (see Operator's Manual). A permanent hard copy (printout) of the data should also be kept on file.
- A more detailed description of the TDR operation is included in the Operator's Manual.

6.2 FDC

- Turn FDC control unit on, update internal clock and calendar as needed.

- Set the **MEASUREMENT UNITS** by scrolling through **SPECIAL FUNCTION** until **GAUGE UNITS** is reached.

- Enable probe calibration by pressing **CALIB./OFFSET**.

- Take a measurement by selecting **START/ENTER**. After a 15 second measurement, select **YES** if the data is to be stored.

- Save all field data as needed using the on-board data logger and periodically download saved data onto a personal computer (see Operator's Manual). A permanent hard copy (printout) of the data should also be kept on file.

- A more detailed description of the FDC operation is included in the Operator's Manual.

7.0 INSTRUMENT CALIBRATION VERIFICATION

This section details the construction and use of known volumetric water content test cell standards to be used as calibration verification tools. Each of the instruments described in this SOP are factory calibrated prior to delivery. Use of the test cells described below will be limited to field verification of instrument calibration.

7.1 MATERIALS AND EQUIPMENT

- Mass Balance accurate to 0.1 grams
- 100 ml Graduated Cylinder
- Large stainless steel mixing bowl

- Deionized water 1-2 gallons
- Stainless trowel and spatula
- Electric drill with assorted drill bit sizes
- Two (2) Sentry 200 FDC probes with cable
- Two (2) wave guide assemblies (TDR) with cable
- Four (4) 6-inch diameter, 12-inch length segments of Schedule 40 PVC Blank Casing
- Four (4) Schedule 40 PVC, 6-inch casing slip caps
- Four (4) Schedule 40 PVC, 6-inch casing end plugs
- Weighing trays QTY ~ 20
- One (1) 100-lb. sack of 60-mesh silica sand
- Four (4) ¼ inch-inch NPT brass valves

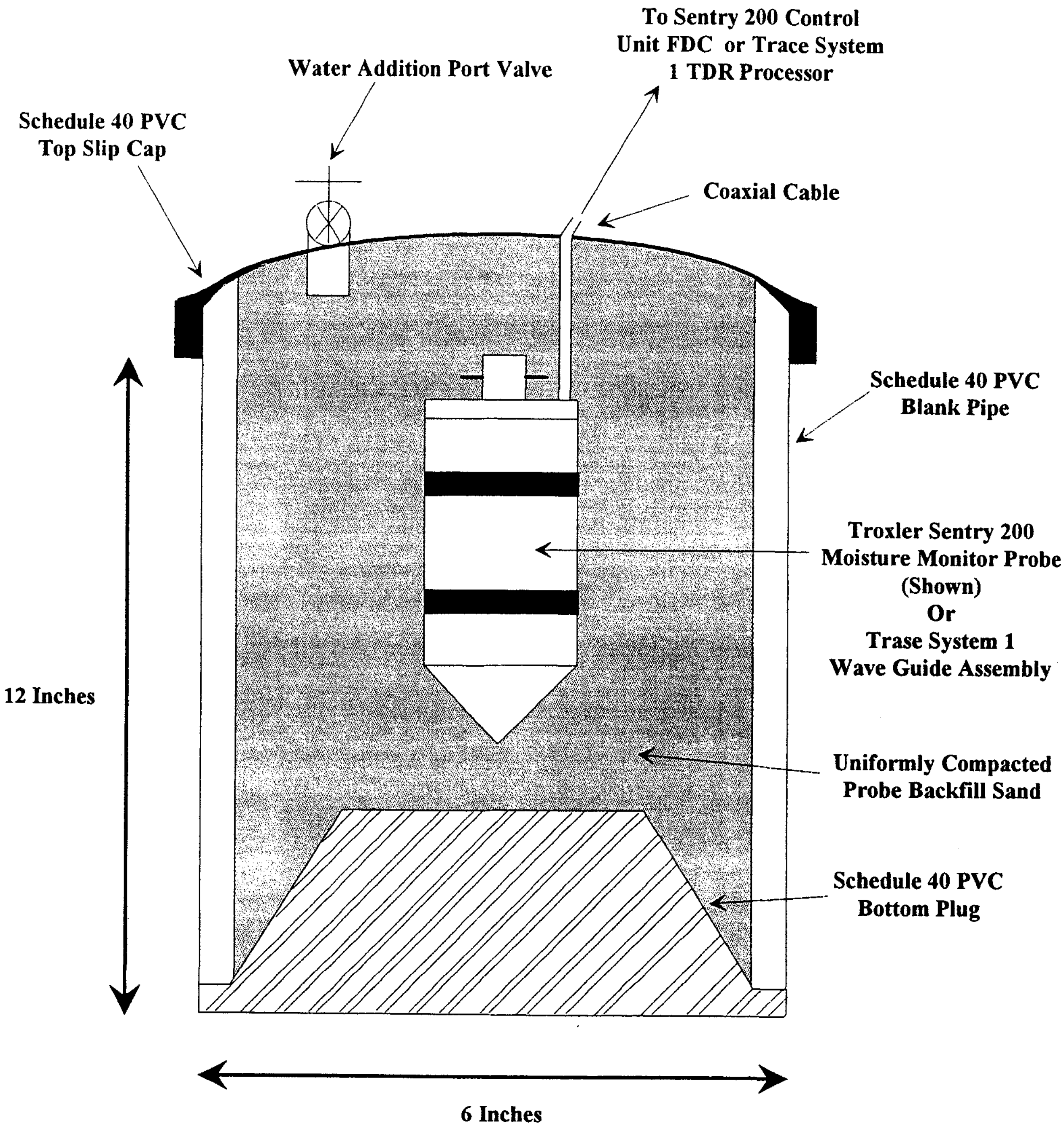
7.1.1 Construction of Test Cells

The following steps outline the construction of four known volumetric water content test cells for field calibration verification standards.

- Label the four (4) segments of blank casing, and top slip caps A and B (for FDC) and C and D (for TDR), respectively.
- Position the four (4) PVC end plugs at the bases of A, B, C, and D, respectively.

- Using the electric drill and appropriate diameter bits, drill a single hole into the PVC top slip caps A and B for FDC probe cable access; and a single hole in the remaining two (2) PVC slip caps C and D to serve as an anchor point for TDR wave guide installation (see Figure SOP VZ.4-1). A third hole with ¼-inch NPT threading will be machined into each cap for water addition via a valve fitting.

- Attach the coaxial cables to the two (2) FDC probes and the two (2) TDR wave guide assemblies and position into test cells A, B, C, and D.



Note: Figure not drawn to scale

#60 Mesh Silica Sand

Prepared For
U.S. Department of Energy
Rocky Flats Plant, Golden, Colorado

Figure SOP VZ.4-1
Instrument Calibration
Test Cell Standard
RFP OU4 Solar Ponds

- Fill test cells with previously weighed, masses of loam soil from mixing bowl and compact sand using spatula. When the test cells are filled to the upper cell height with compacted soil, secure top slip caps in place and weigh and record the mass of each test cell.

- Add deionized water using the graduated cylinder to test cells A and C such that a 10% by volume water content is attained.

- Add deionized water from the graduated cylinder to test cells B and D such that a volumetric water content of 30% is attained.

- Reweigh test cells A, B, C, and D, actual volumetric water contents, and record prior to use as calibration verification standards.

7.2 CALIBRATION VERIFICATION PROCEDURES

7.2.1 TDR Calibration Verification

Because the TDR unit is pre-calibrated prior to shipment from the manufacturer, calibration will be limited to recording responses from previously compared field calibration verification standards (Section 7.1.1).

For routine calibration verification procedures, refer to Trace System 1 Operator's Manual.

7.2.2 FDC Calibration Verification

Because the FDC unit is pre-calibrated prior to shipment from the manufacturer, calibration will be limited to recording responses from previously compared field calibration verification standards (Section 7.1.1).

For routine calibration verification procedures, refer to Troxler Sentry 200 Moisture Monitor Operator's Manual.

8.0 DECONTAMINATION

Excavation/boring equipment will be decontaminated prior to excavating each trench or pit, or prior to initiating each augured boring, and at the conclusion of the operation. Sampling probe installation equipment will be decontaminated prior to initiating each installation. Care should be taken to inspect and monitor all excavation equipment, especially the backhoe, to ensure that no hydraulic and/or fuel leaks add contaminants to the site.

Specific decontamination procedures are described in SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination.

9.0 DOCUMENTATION

All field information required by this SOP will be documented in the field notebook. As a minimum, the date, time, scientist's initials, station designation, and instrument output parameters (water content, wave guide length) will be recorded during each event. Field observations and data will be recorded with black waterproof (permanent) ink on the field data forms.

SOP VZ.5

PROCEDURE FOR TRANSDUCERS IN WELLS

PROCEDURE FOR TRANSDUCERS IN WELLS

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant to measure groundwater levels in wells using transducers.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel performing groundwater level measurements will be field technicians, soil scientists, geologists, hydrologists, or geotechnical engineers with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following reference was reviewed prior to the preparation of this procedure:

> ASTM, 1988, Standard Test Method for Determining Subsurface Liquid Level in a Borehole or Monitoring Well, ASTM Standard D4750-87.

4.2 INTERNAL REFERENCES

The following SOPs are referenced by this procedure:

- SOP GW.01, Water Level Measurement
- SOP GT.06, Monitoring Wells and Piezometer Installation
- SOP GT.06, Monitoring Wells and Piezometer Installation
- SOP FO.03, General Equipment Decontamination

5.0 PROCEDURE FOR WATER LEVEL MEASUREMENT USING TRANSDUCERS

Wells and piezometers used for groundwater level measurement shall be constructed according to SOP GT-06, Monitoring Well and Piezometer Installation. Water level measurements using transducers shall be carried out in accordance with the applicable portions of SOP GW-01, Water Level Measurement, and ASTM Standard D4750-87, Standard Test Method for Determining Subsurface Liquid Level in a Borehole or Monitoring Well.

6.0 DECONTAMINATION

Decontamination procedures are described in SOP FO.03, General Equipment Decontamination.

7.0 DOCUMENTATION

Information required by this SOP will be documented on a Groundwater Level Measurement Form (Form GW.01A).

S0P VZ.6

PROCEDURES FOR DETERMINATION OF BULK DENSITY

PROCEDURE FOR THE DETERMINATION OF BULK DENSITY

PROCEDURES FOR DETERMINATION OF BULK DENSITY

2.0 PURPOSE AND SCOPE

This Standard Operating Procedure (SOP) describes procedures that will be used to determine in-place density of soil by the drive-cylinder method. All activities will be conducted in accordance with the Heath and Safety Plan (HSP) that will be developed for these activities.

3.0 QUALIFICATIONS

Personnel performing in-place soil density measurements will be geologist, hydrologist, soil scientist, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCE

ASTM Standard D 2937-83, Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP GT.7, Logging and sampling of test pits.
- SOP FO.3, General Equipment Decontamination

5.0 PROCEDURES

5.1 MATERIALS AND EQUIPMENT

- Drive Cylinders with diameters from 2 to 5 1/2 in.
- Drive Head
- Straightedge
- Auger
- Shovel
- Balance or scale accurate to 1.0g
- Weighing trays
- Drying Equipment
- Sledgehammer

5.2 PROCEDURES FOR SAMPLING AT OR NEAR SURFACE

Clear the preselected location of all loose particles. Record location of each test in field notebook. Drive cylinder and drive head into the soil by raising the drop hammer and allowing it to fall. Continue driving until the top of the cylinder is approximately 1/2 inch below the surface. Care will be necessary to prevent overdriving, which will result in compressing the sample. Remove the drive head and dig the cylinder from the ground with a shovel. Trim any excess soil from the sides and ends of the cylinder with a straightedge. If the cylinder is not full or is deformed, discard the sample. Immediately determine the mass of the sample and water content or seal in container which will prevent soil or water loss until mass and water content can be determined.

5.3 PROCEDURE FOR SAMPLING BELOW THE SURFACE

Drill a hole with an auger the desired layer or elevation to be sampled. Clean out the bottom of the hole. Assemble the cylinder to the drive head (with extensions if needed) and lower cylinder to bottom of hole. Drive cylinder into soil until top of cylinder is 1 inch below surface being sampled. Break the sample from the ground by moving the rod back and forth and remove from the hole. In cases where the sample breaks from the ground slightly above the cutting edge, the sample may be pushed back to the bottom by pressing the top of the sample with a flat surface. Trim any excess soil from the cylinder and determine the mass and water content or seal in a container for latter determination.

5.4 PROCEDURE FOR DETERMINING BULK DENSITY

Determine mass of the drive cylinder and soil sample to the nearest 1g and record. Remove the soil sample from the cylinder and determine water content. The dry mass (M_3) of the cylinder sample, expressed in grams, is as follows:

$$M_3 = [(M_1 - M_2)/(100 + w)] \times 100$$

where:

M_3 = sample dry mass, g
M_1 = mass of cylinder + wet sample, g
M_2 = mass of cylinder, g
w = water content, %, dry mass basis

$$\frac{M_3}{v} = lb$$

where:

v = volume cylinder, cm^3
lb = bulk dry density, g/cm^3

6.0 DECONTAMINATION

All soil sampling and preparation equipment will be decontaminated prior to and following each sample event according to SOP F0.3, General Equipment Decontamination.

7.0 DOCUMENTATION

Documentation of each sampled location will include the following:

- Location
- Depth below ground surface
- Dry density
- Water content
- Dimensions and volume of sampler
- Visual description of soil sample
- Comments on soil sample disturbance

All records will be entered in black waterproof ink on the record forms and field book.

SOP VZ.7

PROCEDURE FOR NEUTRON MOISTURE LOGGING

PROCEDURE FOR NEUTRON MOISTURE LOGGING

NEUTRON MOISTURE LOGGING

2.0 PURPOSE AND SCOPE

This Standard Operating Procedure (SOP) describes the procedures that will be used to measure hydrogen-bearing substances in the subsurface with a neutron moisture probe. This SOP describes the calibration and use of the neutron probe for quantitative measurement of moisture in soil. In situations where neutron probe is to be used for qualitative, comparative purposes, the calibration steps described in Sections 5.1, 5.2, and 5.3 may be omitted.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel performing neutron moisture logging will be field technicians, geologists, soil scientists, hydrologists, or geotechnical engineers who are certified in the operation of the neutron moisture probe and who have an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following references were reviewed prior to writing this procedure:

Kramer, J.H., Cullen, S.J., and Everett, L.G., 1992, Vadose Zone Monitoring with the Neutron Moisture Probe: Ground Water Monitoring Review, v. 12, n. 3.

ASTM, 1988, Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth), ASTM Standard D 3017-88.

ASTM Standard D 2216-80, Standard Method for Laboratory Determination of Water (Moisture) content of Soil, Rock, and Soil Aggregate Mixtures.

Everett, L.G., Hoylman, E.W., Wilson, L.G., 1984, Vadose Zone Monitoring for Hazardous Waste Sites: Noyes Data Corp. Park Ridge, New Jersey, 358 p.

Keller, B.R., Everett, L.G., and Marks, R.J., 1990, Effects of Access Tube Material and Grout on Neutron Probe Measurements in the Vadose Zone: Groundwater Monitoring Review, v. 10, n.1.

4.2 INTERNAL REFERENCES

The following SOPs are cited in this procedure:

- SOP FO.03, General Equipment Decontamination
- SOP GT.06, Monitoring Well and Piezometer Installation
- SOP GT.02, Drilling and Sampling Using Hollow-Stem Auger Technique

5.0 PROCEDURES

Neutron moisture logging utilizes a radioactive source which emits fast neutrons. The neutrons are moderated, or slowed by collisions with surrounding, low-molecular weight atoms (primarily hydrogen). The slow, or "thermalized" neutron may then be absorbed or captured by receptive atoms. If a neutron has lost enough kinetic energy, it may react with boron-trifluoride or helium-3 gas in the probe detector, which generates an electric pulse. The rate of electric pulse generation in the detector can be correlated to the hydrogen content of the medium being tested. Because water and, perhaps hydrocarbons in contaminated areas, are the primary sources of hydrogen in the subsurface environment, changes in pulse generation rates can be correlated to changes in soil moisture content.

5.1 INSTRUMENT CALIBRATION

For quantitative measurements, the neutron probe must be calibrated with test measurements in soils of known moisture content. The initial calibration procedure for the neutron moisture probe at the Rocky Flats Plant shall be performed according to the following procedure:

a) A site will be selected with uniform geologic material similar to the material to be tested.

b) An access tube will be constructed using materials and techniques identical to those to be used during site measurements.

c) A neutron counting interval appropriate for the desired precision will be selected. Sixteen seconds is typically used with 50 miC devices, although testing at the site may suggest that 4 or 8 second intervals can be used without loss of accuracy. At least 32 readings will be taken with the center of the neutron probe detector at least 0.5 meters beneath the surface. The mean value of all the readings will be calculated.

d) The volumetric water content of the soil from the test plot will be estimated from the mean of five samples adjacent to the access tube measured using standard laboratory techniques described in ASTM Standard D 2216-80, Standard Method for Laboratory Determination of Water (Moisture) content of Soil, Rock, and Soil Aggregate Mixtures.

e) Steps a-d will be repeated at least four times (for a total of at least five measurements) at different moisture contents that span the full range of the moisture capacity of the geologic material under investigation.

f) Approximately 200 liters of the geologic material that was tested in Steps a-e will be prepared by oven drying the material at 105°C for at least 24 hours.

g) The dried soil will be placed in an appropriate vessel which will be fitted with a centered neutron probe access tube identical to the one used in the test plot. The soil will be compacted to approximately its natural density.

h) The soil-filled vessel will be sealed against vapor intrusion, which could introduce moisture into the dry soil.

i) A set of at least 32 neutron probe readings will be collected with the detector centered in the access tube. The mean of all the dry soil neutron readings will be recorded.

j) A linear regression line will be calculated relating neutron counts to measured soil moisture, using all calculated mean valves, including the mean value from the dry soil vessel. This completes the initial calibration procedure.

5.2 TRANSFER STANDARDS

Wet and dry transfer standards will be used to transfer the initial calibration to additional neutron probes, and to recalibrate the original probe, which may exhibit electronic drift over time. The procedure for constructing and using transfer standards is described below:

a) The dry transfer standard shall be the vessel of dry soil described in Section 5.1. The wet (high-hydrogen content) transfer standard shall be the same shape, size, and material as the dry standard, preferably a cylinder, at least 0.5 meters in diameter and 0.8 meters high, filled with a material with a high hydrogen content, such as water, wax, or plastic and sealed against vapor intrusion. Both transfer standards shall be fitted with neutron probe access tubes of the same materials as that to be used in subsurface investigations.

b) A neutron counting interval will be selected. This should be the same interval used for the initial instrument calibration, unless it has been demonstrated that a shorter counting interval is satisfactory for the site.

c) The neutron probe will be positioned in the center of the dry transfer standard access tube and at least 32 readings will be recorded. This procedure will be repeated for the wet transfer standard.

d) To check for probe precision, the mean ($\bar{x}$) and standard deviation (s) of each set of 32 readings from step c will be calculated If the ratio: $s/\sqrt{\bar{x}}$ is between 0.75 and 1.25, probe precision is acceptable. If not, Step C should be repeated. If the probe precision is unacceptable on two successive trials, the instrument should be maintained or repaired.

e) The hydrogen content of each transfer standard will be estimated using the regression equation developed in Section 5.1.j.

5.3 RECALIBRATION

The neutron probe will be retested in the wet and dry transfer standard at the beginning and end of each neutron logging field event.

a) Using the same counting interval which was used in the initial calibration (typically, 16 seconds), at least 32 measurements in both the wet and the dry transfer standard will be collected.

b) The new mean ($\bar{x}_{new}$) and standard deviations (s_{new}) for the n number of measurements in each transfer standard will be calculated.

c) A t-test will be performed to evaluate if the new and old sample means for each standard are statistically equivalent. If $\bar{x}_{new}$ fails the test, a new calibration relationship will be defined as a straight line between the data pairs representing the new standard counts at the predetermined moisture contents for each standard.

5.4 NEUTRON MOISTURE LOGGING

Neutron probe access tubes shall be installed in accordance with SOP GT.06, Monitoring Well and Piezometer Installation or by other means to be developed later.

Neutron probe access tubes may be unscreened, or they may be screened to serve as piezometers. Because moisture in grout can mask environmental moisture conditions, the length of grouted intervals will be kept to a minimum, grout will be mixed with the minimum amount of water necessary for emplacement, and grout will be allowed to cure at least ten days to allow its moisture content to stabilize.

Neutron moisture logs will be made by collecting data from evenly-spaced intervals along the access tube (usually 1 foot intervals). Count times shall be 16 seconds, unless it has been demonstrated at the site that shorter count times give satisfactory results. At least two measurements will be made at each interval. If counts differ by more than ten percent, then two additional readings will be recorded. If counts continue to differ, a case standard will be performed to check for instrument malfunction.

Transfer standards will be run at the beginning and end of each neutron logging field event.

Case standards will be run at the beginning and end of each day that the probe is being used. Case standards will be performed according to the manufacturer's guidelines. If case standards differ by more than ten percent, transfer standards will be run to assess instrument calibration.

SOP VZ.8

PROCEDURE FOR MEASURING IN-SITU HYDRAULIC CONDUCTIVITY USING THE BAT SYSTEM

A STANDARD OPERATING PROCEDURE FOR MEASURING IN-SITU HYDRAULIC CONDUCTIVITY USING THE BAT® SYSTEM IS CURRENTLY UNDER DEVELOPMENT BY EG&G. MODIFICATIONS SPECIFIC TO THE OU4 VADOSE ZONE INVESTIGATION WILL BE INCORPORATED INTO THESE DRAFT STANDARD OPERATING PROCEDURES, OR WILL BE IMPLEMENTED AS DOCUMENT CHANGE NOTICES.

SOP VZ.9

PROCEDURE FOR BOREHOLE PERMEABILITY TESTS

THE STANDARD OPERATING PROCEDURE FOR BOREHOLE PERMEABILITY TESTS IS NO LONGER REQUIRED FOR THE OU4 VADOSE ZONE INVESTIGATION

SOP VZ.10

PROCEDURE FOR LYSIMETER INSTALLATION AND SAMPLING

PROCEDURE FOR LYSIMETER INSTALLATION AND SAMPLING

Figures

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to install and sample from soil interstitial water samplers called lysimeters.

3.0 QUALIFICATIONS

Personnel installing and sampling lysimeters will be geologists, hydrologists, hydrogeologists, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to writing the procedures for soil sampling:

- ASTM Standard D 1452-80, Standard Practice for Soil Investigation and Sampling by Auger Borings

- Draft ASTM Standard Guide for Pore-Liquid Sampling from the Vadose Zone

- Operating instructions for models 1920 and 1940, pressure-vacuum soil water samplers. Soilmoisture Equipment Corporation, Santa Barbara, California.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP include the following:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples
- SOP GW.5, Field Measurement of Groundwater Field Parameters
- SOP GW.6, Groundwater Sampling
- SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations
- SOP GT.20, Procedures for Soil Interstitial Water Sampling and Sampler Installation

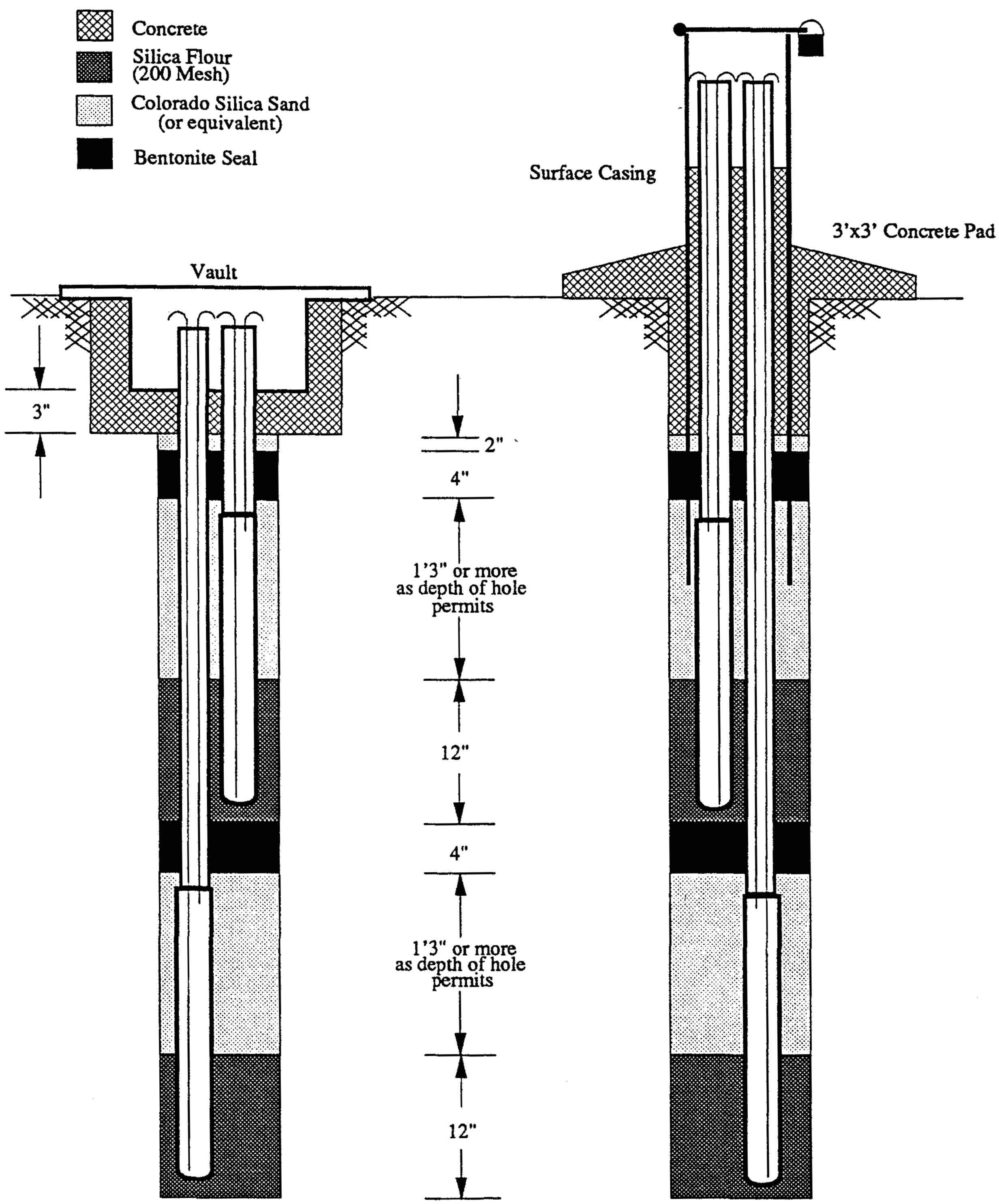
5.0 PROCEDURES FOR LYSIMETER INSTALLATION

Tension soil solution samplers or suction lysimeters consist of a hollow porous ceramic cup attached to a sample vessel. Figure SOP VZ.10-1 shows a lysimeter installed in a borehole. Water samples are obtained by applying suction to the sampler that draws interstitial waters into the sample vessel.

There are no maintenance requirements for the soil water samplers except protecting the access tube from physical damage. Freezing conditions will not damage the samplers. The samplers are normally left permanently in place throughout the year.

5.1 MATERIALS AND EQUIPMENT

- Ceramic lysimeter
- Portable pump
- Collection bottles
- Polyethylene tube



Note: Indicated values represent minimum dimensions

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FIGURE SOP VZ.10-1

TYPICAL LYSIMETER INSTALLATION
SOLAR PONDS – OU4

- Stainless steel trowel
- 2-mm sieve and bottom pan
- Stainless steel mixing rod
- Mixing bowl
- Distilled water
- Portland cement
- Bentonite
- Borehole depth sounding equipment
- PVC tremie pipe

5.2 PROCEDURES

5.2.1 Pre-installation

New samplers may be contaminated with dust during manufacturing and therefore EPA manual 530-SW-86-040 recommends preparation of the ceramic samplers using the following procedure:

- The lysimeters have to be cleaned before installation. The cleaning procedure is performed in acid and distilled water baths. Install polyethylene tubes through the top of the lysimeter, ensuring that one of the tubes extends to the bottom of the cup. Connect the lysimeter to a pump and pass approximately 200 ml of 1N hydrochloric acid (HCl) through the porous section of the sampler.

- Flush distilled water through the porous section to clean the sampler from acid residue. The flushing process will continue until the specific conductance of the outflowing water is within 2 percent of the inflowing water.

- During the cleaning operation, the porous section and fitting of individual samplers will be checked for leaks and faulty seals. This will be accomplished by setting a vacuum in each sampler and observing if the vacuum is maintained over a 30-minute interval.

- After cleaning, the samplers will be placed in clean plastic bags to prevent contamination during transport to the field.

- Upon arrival to the installation location, and immediately prior to installation, the porous section of the sampler will be placed in distilled water for about 30 minutes to saturate the sampler.

5.2.2 Installation

The goals of installation are to ensure good hydraulic contact between the sampler and the soil, and to minimize leakage of waters along the outside of the sampler. The following steps will be performed to correctly install the lysimeters:

- Excavate a soil boring to the desired depth of the sampling interval.

- Depth sound the boring and measure the lysimeter to the nearest 100th of a foot to ensure precise placement of the sampler. Vacuum test the lysimeter before installation into the boring.

- Attach a PVC riser pipe to the top of the lysimeter to encase the sample and vacuum tubes (optional).

- Place a centralizer or decentralizer at the center of the lysimeter to control the location in the borehole (optional).

- Install the lysimeter into the boring at the appropriate depth.

- Tremie in a quantity of 200-mesh silica flour slurry through a PVC tremie pipe. The quantity of silica flour slurry must be adequate to surround the entire cup of the lysimeter and a portion of the body of the lysimeter.

- After allowing the silica flour to "set up," install a minimum one-foot thick layer of inert material (e.g. Colorado Silica Sand) in the annular space above the silica flour.

- Add a minimum 4-inch seal of pure bentonite above the inert material.

- Vacuum test the lysimeter before the remainder of the hole is plugged.

- Backfill to within a foot of the surface with inert material (e.g. Colorado Silica Sand).

- Complete the borehole to prevent surface water from entering. Completion should be either flush- or surface-cased depending on the location of the borehole.

6.0 COLLECTION OF WATER SAMPLES FROM THE LYSIMETER

6.1 MATERIALS AND EQUIPMENT

- Vacuum hand-held pump
- Filters (0.45, 0.22, and 0.1 um) (optional)
- Filtration device
- Distilled water
- Polyethylene tubes
- Collection bottles precleaned to EPA specifications
- Plastic sheeting
- Logbook
- Sample labels
- Portable laboratory equipment for measuring pH, temperature and specific conductance (optional).

6.2 PROCEDURES

- To collect a sample, the pinch clamp on the discharge access tube is closed and the vacuum port of the pressure-vacuum hand pump is connected to the pressure-vacuum access tube.

- The pump is stroked until the vacuum of approximately 50 to 85 centibars (15" to 25" of mercury) is created within the sampler as read out on the gauge connected to the pump.

- The pinch clamp on the pressure-vacuum access tube is then closed securely to seal the lysimeter under vacuum. The hand pump can then be removed and used for other samplers. The lysimeter is then allowed to collect soil-pore liquid for a period of time.

- To recover a soil water sample, attach the pressure-vacuum access tube to the pressure port on the pump. Place the discharge access tube in a small collection bottle and open both pinch clamps. Apply a few strokes on the hand pump to develop enough pressure within the sampler to force the collected water out of the sampler and into the collection bottle.

7.0 DECONTAMINATION

Excavation equipment will be decontaminated prior to excavating each borehole and at the conclusion of the operation. Sampling equipment will be decontaminated prior to and after collecting each sample. Specific decontamination procedures are described in SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination.

8.0 DOCUMENTATION

All field information required by this SOP will be documented on Forms GT.20A, B and C. Form GT.20A will be used to record data during excavation of the borehole and during soil sampling. Form GT.20B will be used for recording data collected during soil interstitial water sampling. Form GT.20C will be used to record data during filtering of the soil interstitial water sampling. Field observations and data will be recorded with black waterproof (permanent) ink on the field data forms.

APPENDIX C

VADOSE ZONE INVESTIGATION SCHEDULE

WILL BE PROVIDED UNDER SEPARATE COVER

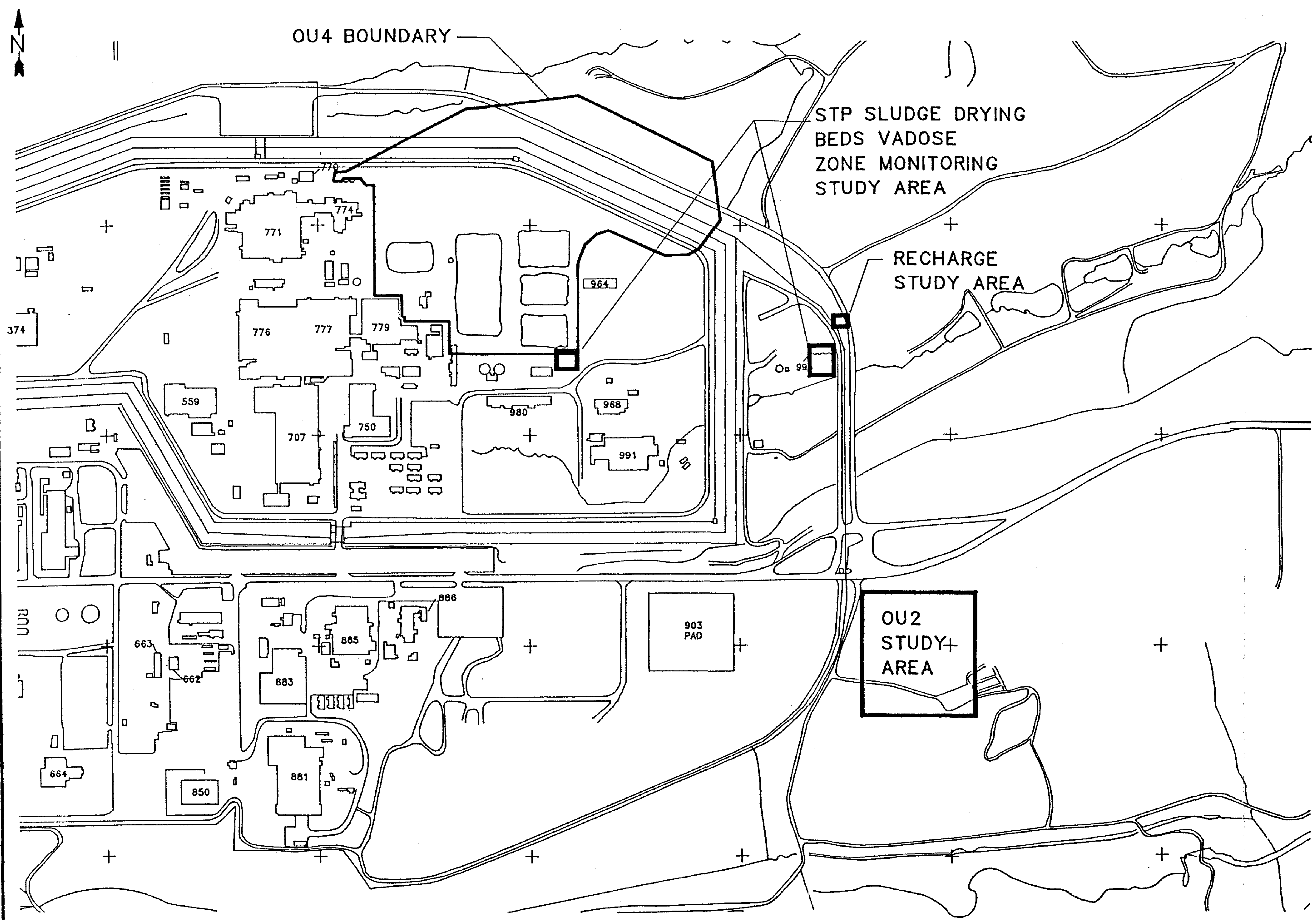

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FIGURE 1-3
LOCATION OF OTHER VADOSE ZONE INVESTIGATIONS SOLAR PONDS - OU4

REVISION NO. 0 | FILE NAME 40101\F01-103.DWG | DATE 12/11/92 | DRAWN BY EMH | APPROVED BY | CHECKED BY

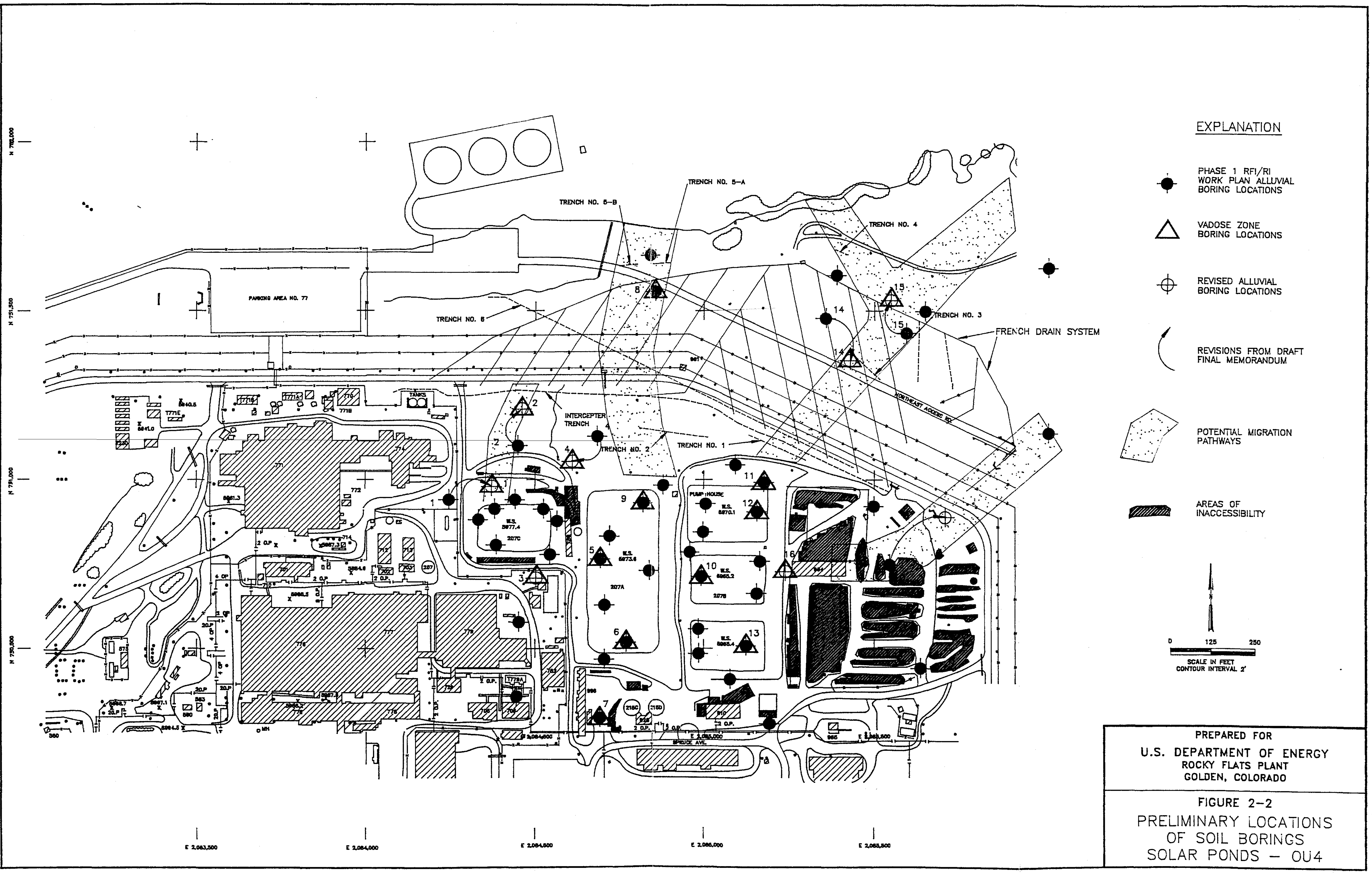

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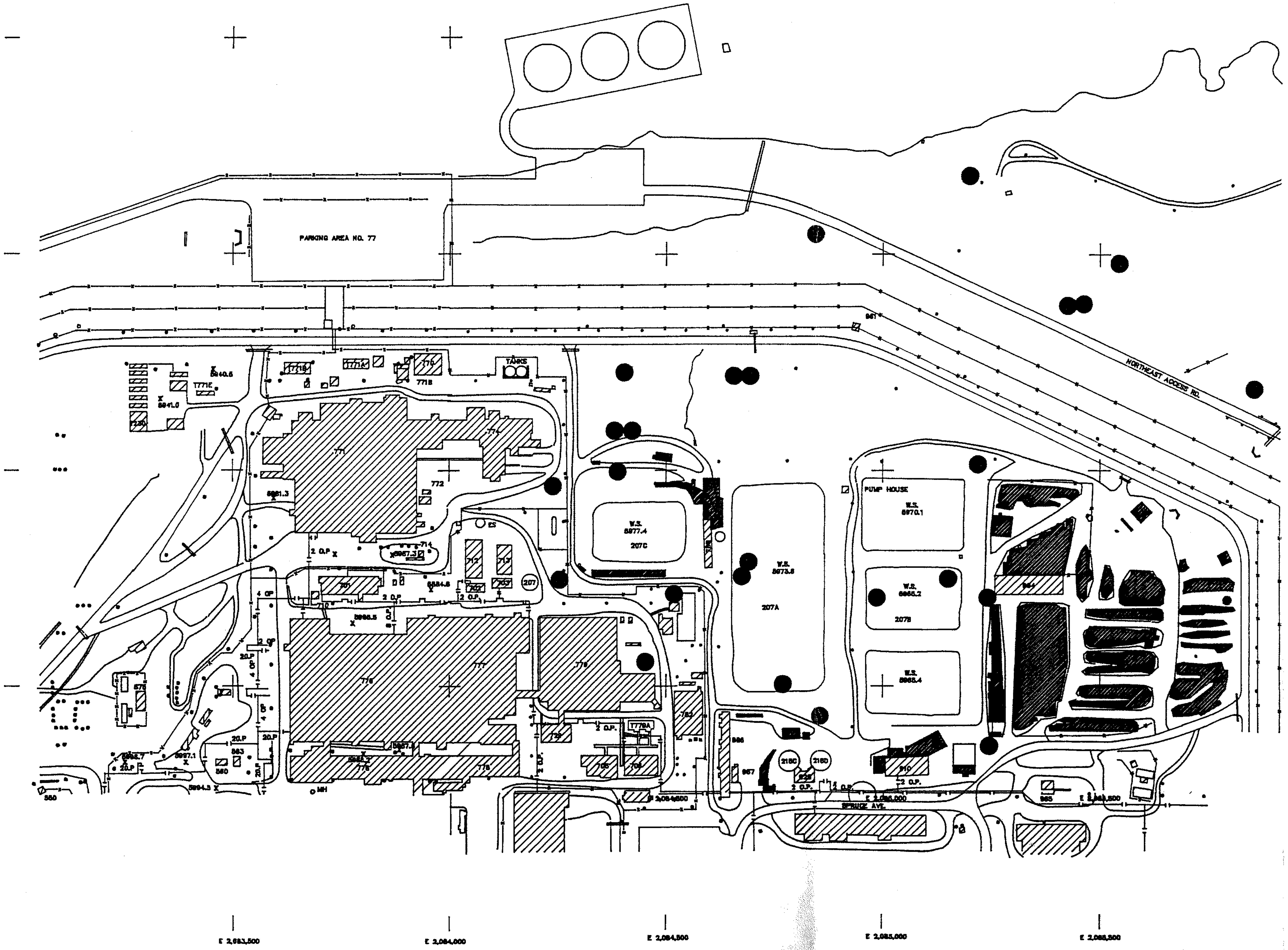
FIGURE 2-2

PRELIMINARY LOCATIONS OF SOIL BORINGS SOLAR PONDS – OU4

REVISION NO. 1 | FILE NAME BORING01.DWG | DATE 12/14/92 | DRAWN BY BC | APPROVED BY AES | CHECKED BY AES



EXPLANATION

● GUELPH PERMEAMETER LOCATIONS

0 125 250
SCALE IN FEET
CONTOUR INTERVAL 2'

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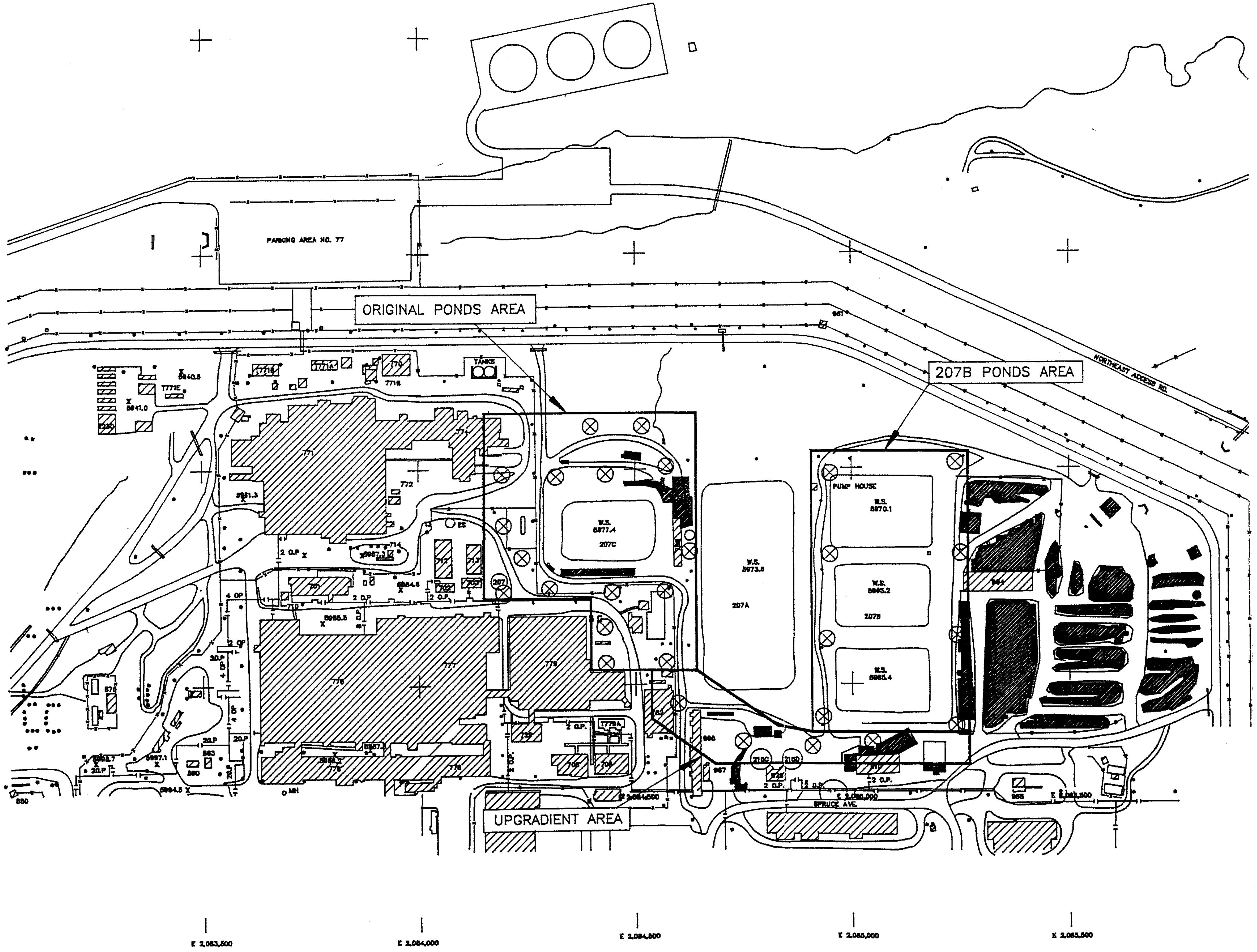
FIGURE 2-3
PRELIMINARY LOCATIONS OF GUELPH PERMEAMETER MEASUREMENTS

CHECKED BY AVS	APPROVED BY ALC	DRAWN BY BC	DATE 12/11/92	FILE NAME GUELPH.DWG	REVISION NO. 0



EXPLANATION

⊗ SOIL GAS SAMPLE LOCATIONS

SG000193 - SG005093

0 125 250
SCALE IN FEET
CONTOUR INTERVAL 2'

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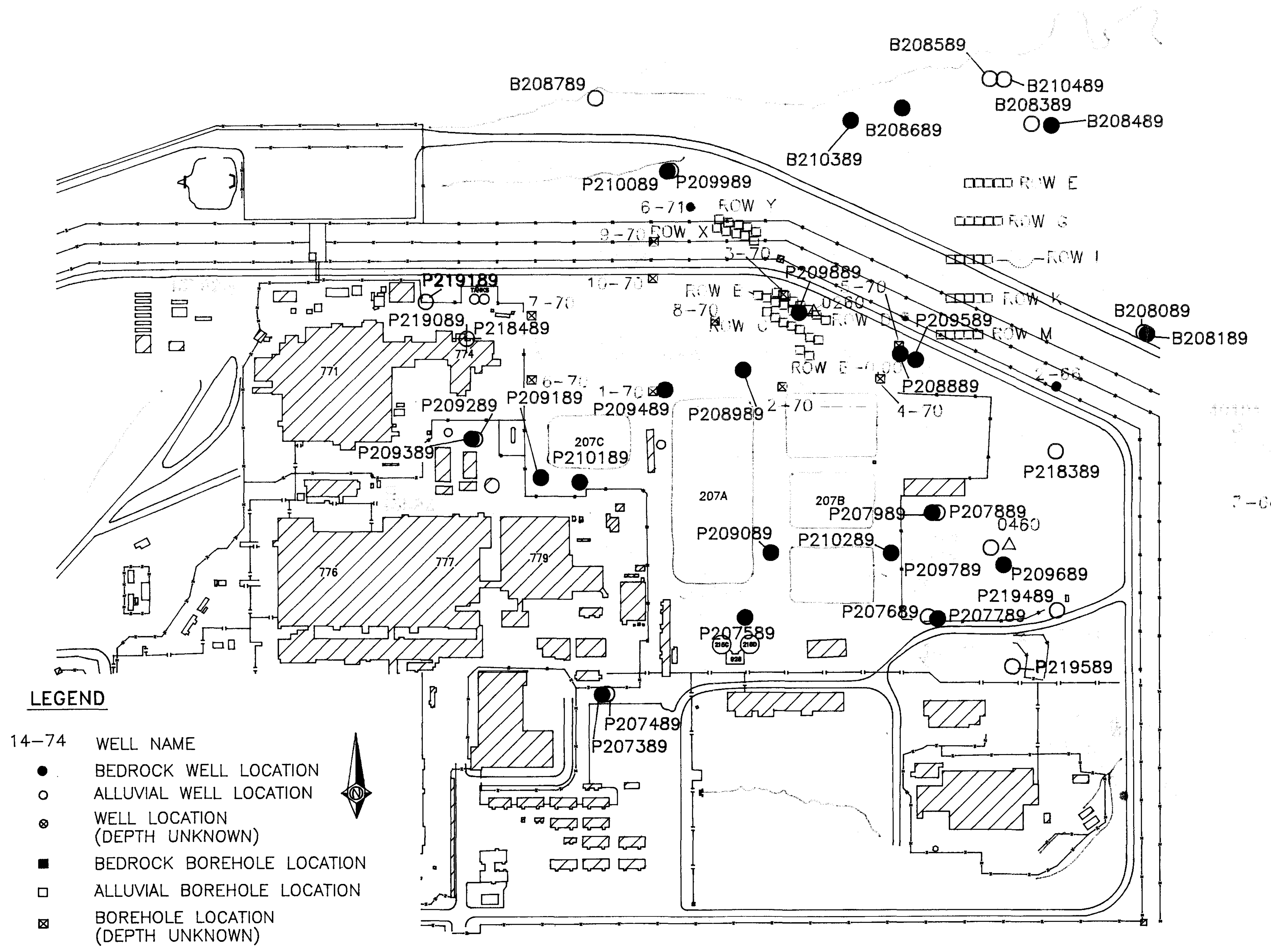
FIGURE 2-4
PRELIMINARY LOCATIONS OF SOIL GAS SAMPLES SOLAR PONDS – OU4

CHECKED BY	APPROVED BY	DRAWN BY	DATE	FILE NAME	REVISION NO.
AKS	AKS	BC	12/11/92	SOILGAS.DWG	0



LEGEND

14-74	WELL NAME
●	BEDROCK WELL LOCATION
○	ALLUVIAL WELL LOCATION
⊗	WELL LOCATION (DEPTH UNKNOWN)
■	BEDROCK BOREHOLE LOCATION
□	ALLUVIAL BOREHOLE LOCATION
⊠	BOREHOLE LOCATION (DEPTH UNKNOWN)

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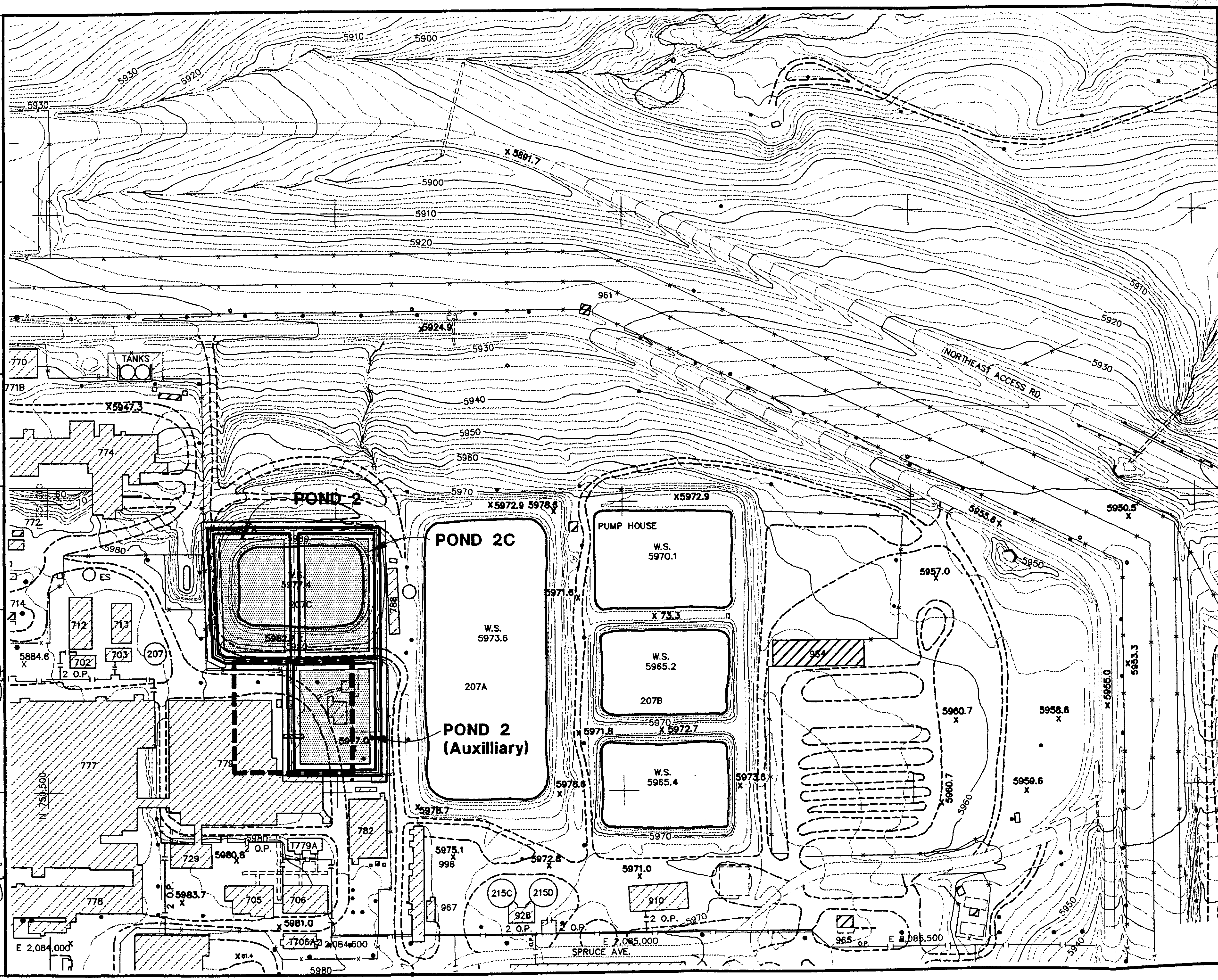
FIGURE A-1

ALL BOREHOLES AT THE SOLAR POND AREA

NOTE: COLORS REPRESENT DIFFERENT DRILLING PROGRAMS.



LEGEND:

LOCATION OF POND 2 (AUXILLIARY) AS INDICATED ON ORIGINAL DRAWINGS

LOCATION OF EARTHEN PONDS AS INDICATED IN 1962 PHOTOGRAPHS

N

CONTOUR INTERVAL 2'

0 200 400
FEET

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FIGURE A-2
APPROXIMATE LOCATIONS OF EARTHEN PONDS SOLAR PONDS - OU4

REVISION NO. 0	FILE NAME 404104.50 VZTN	DATE 12/10/92	DRAWN BY JAA	APPROVED BY	CHECKED BY

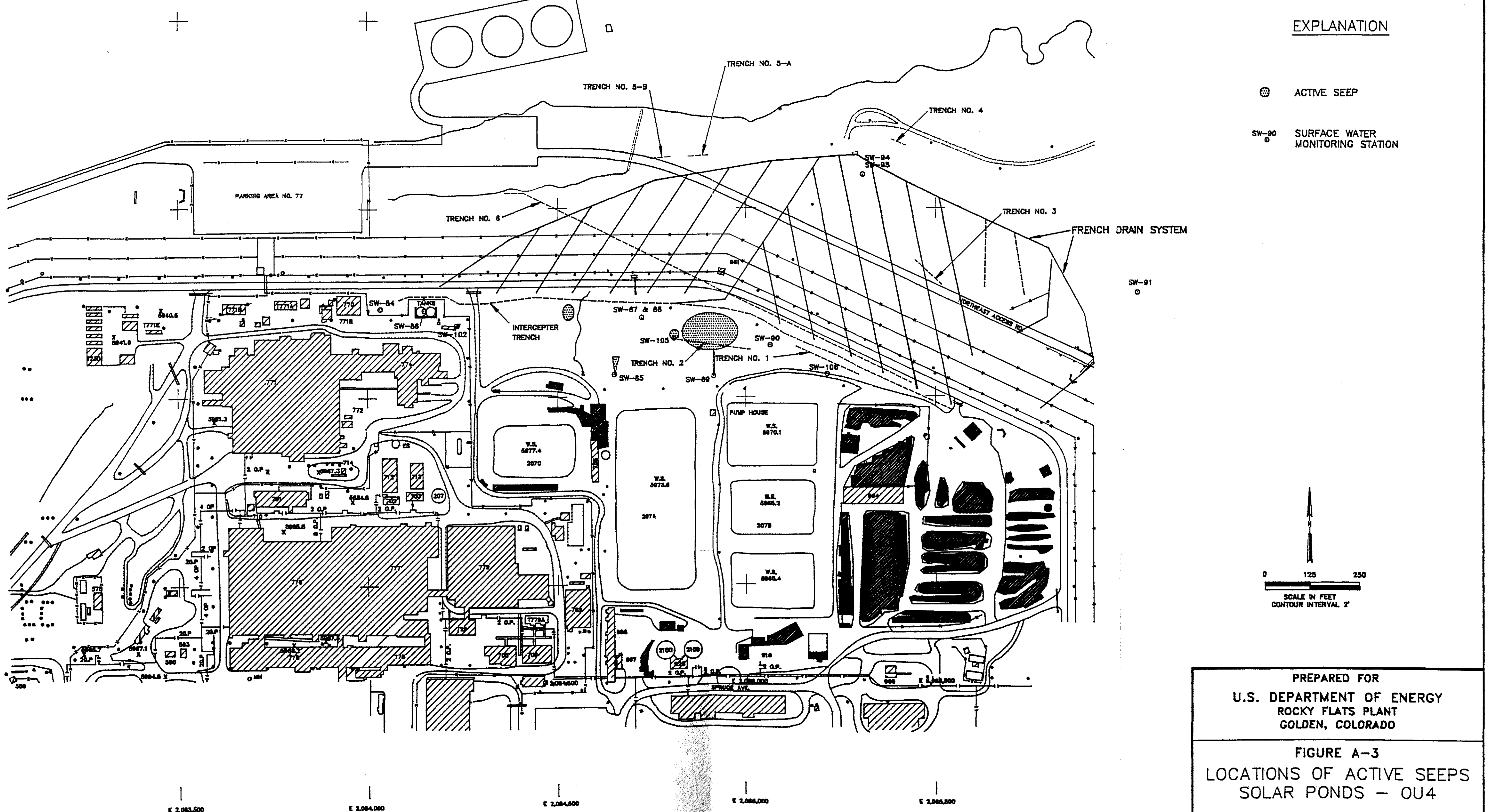

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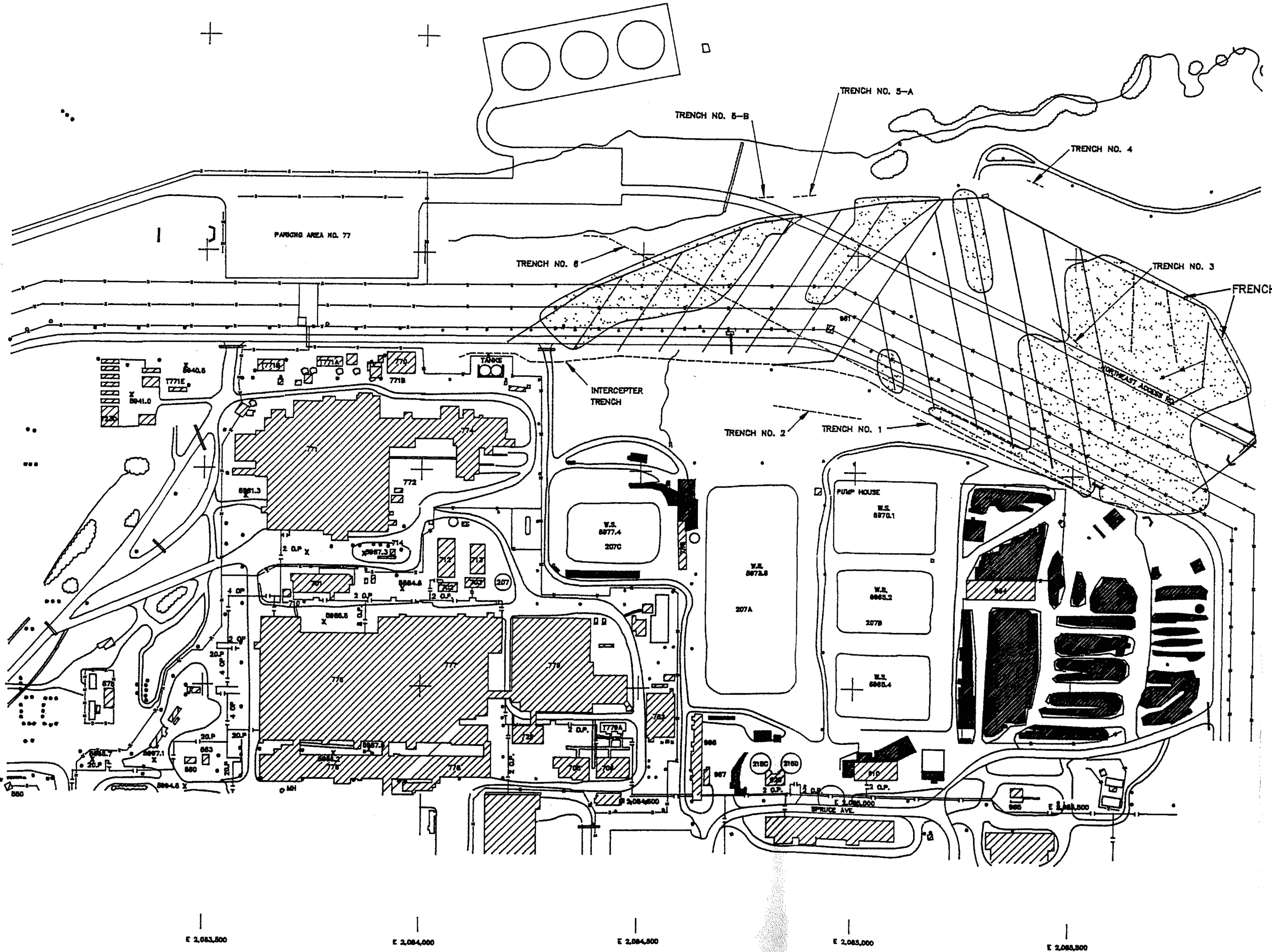
FIGURE A-3
LOCATIONS OF ACTIVE SEEPS
SOLAR PONDS – OU4

CHECKED BY	APPROVED BY	DRAWN BY BC	DATE 12/11/92	FILE NAME SEEPS.DWG	REVISION NO. 0



EXPLANATION

APPROXIMATE LOCATION WHERE THE ITS IS KEYED INTO BEDROCK

0 125 250

SCALE IN FEET
CONTOUR INTERVAL 2'

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FIGURE A-5

ITS CONFIGURATION
SOLAR PONDS – OU4

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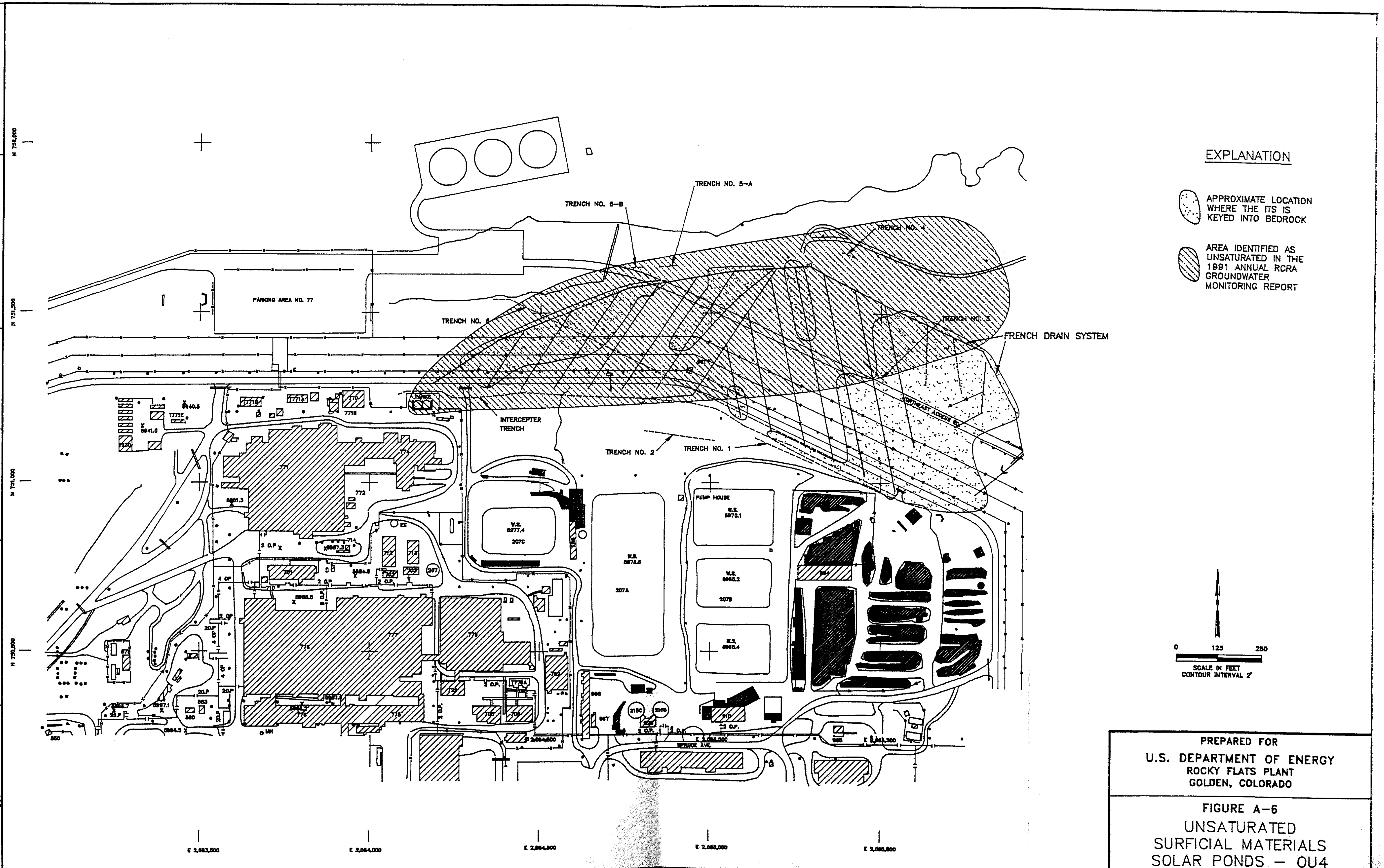

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GOLDEN, COLORADO

FIGURE A-6
UNSATURATED
SURFICIAL MATERIALS
SOLAR PONDS – OU4

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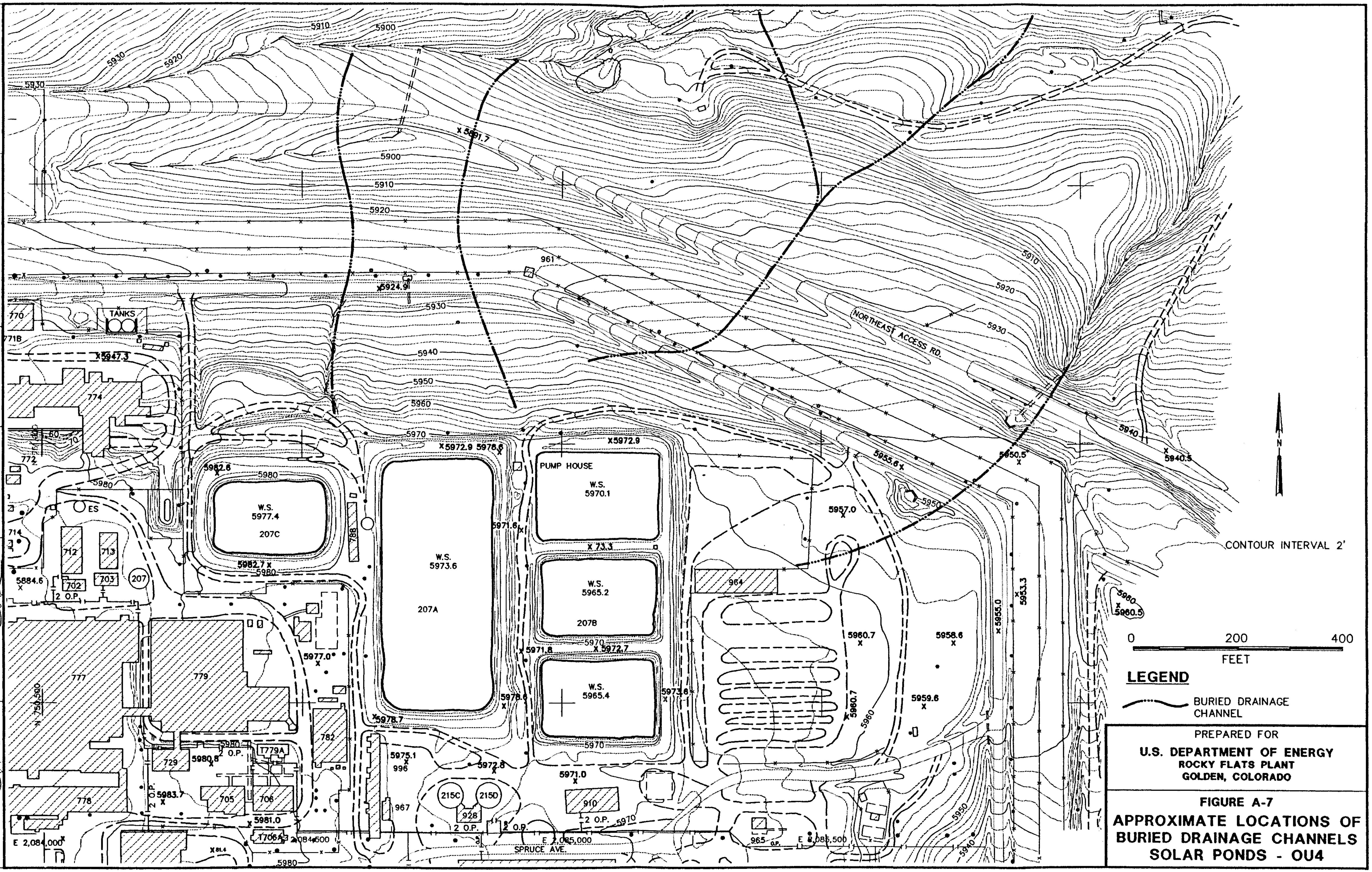

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FIGURE A-7

APPROXIMATE LOCATIONS OF BURIED DRAINAGE CHANNELS SOLAR PONDS - OU4

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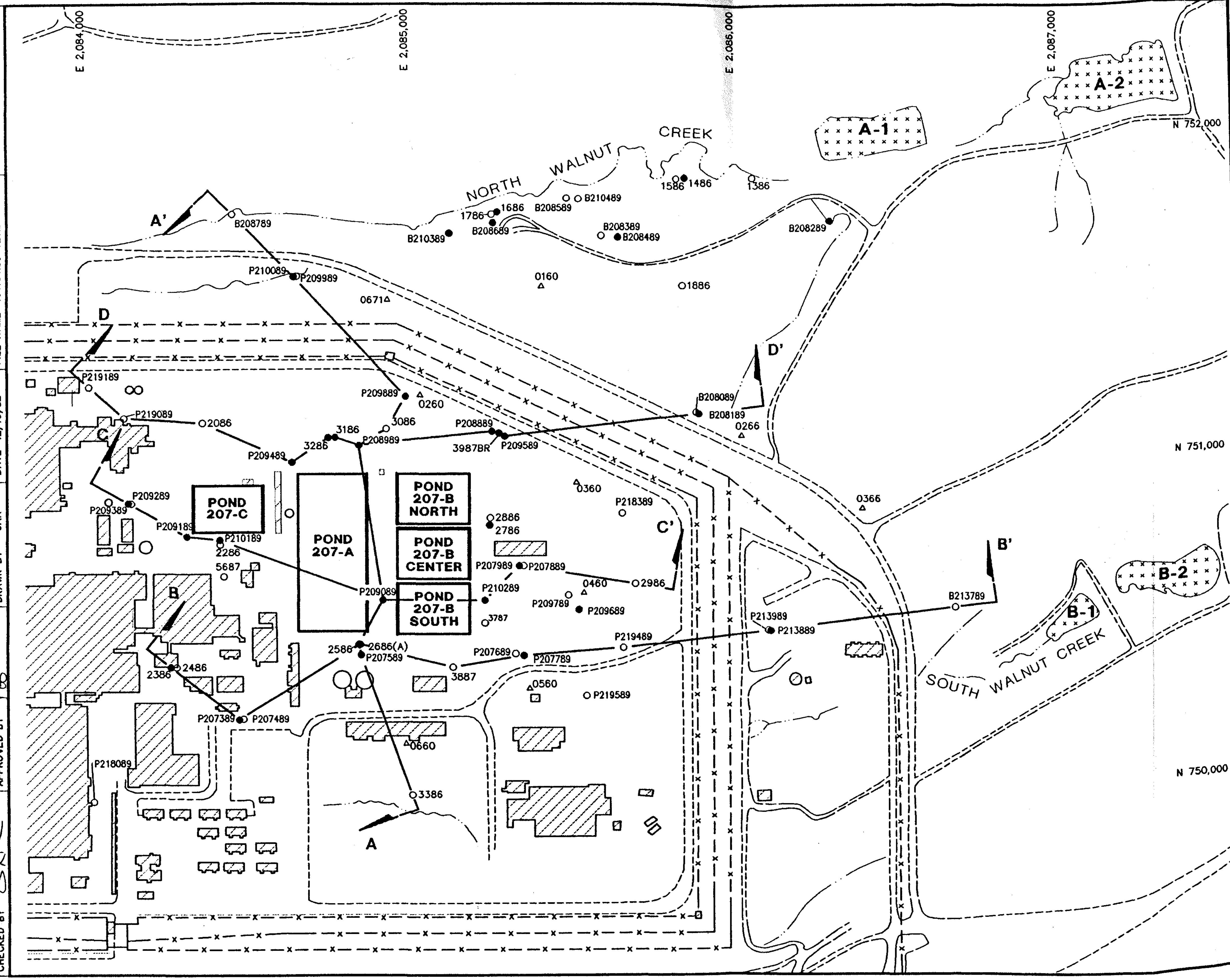
APPROVED BY	[signature]
DRAWN BY	JAA
DATE	12/10/92
FILE NAME	40410450 VZTN
REVISION NO.	0



LEGEND

P218389 ○	ALLUVIAL WELLS
△ 0360	PRE-1986 WELLS
P209489 ●	BEDROCK WELLS
	ROADS
	DRAINAGE / STREAM
	CROSS SECTION LOCATION

SCALE 0 300 600 FEET

SOURCE:
FIGURE 2-9 OF OU4 PHASE 1 RFI/RI WORK PLAN

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FIGURE A-8

LOCATION MAP GEOLOGIC CROSS SECTIONS SOLAR PONDS - OU4

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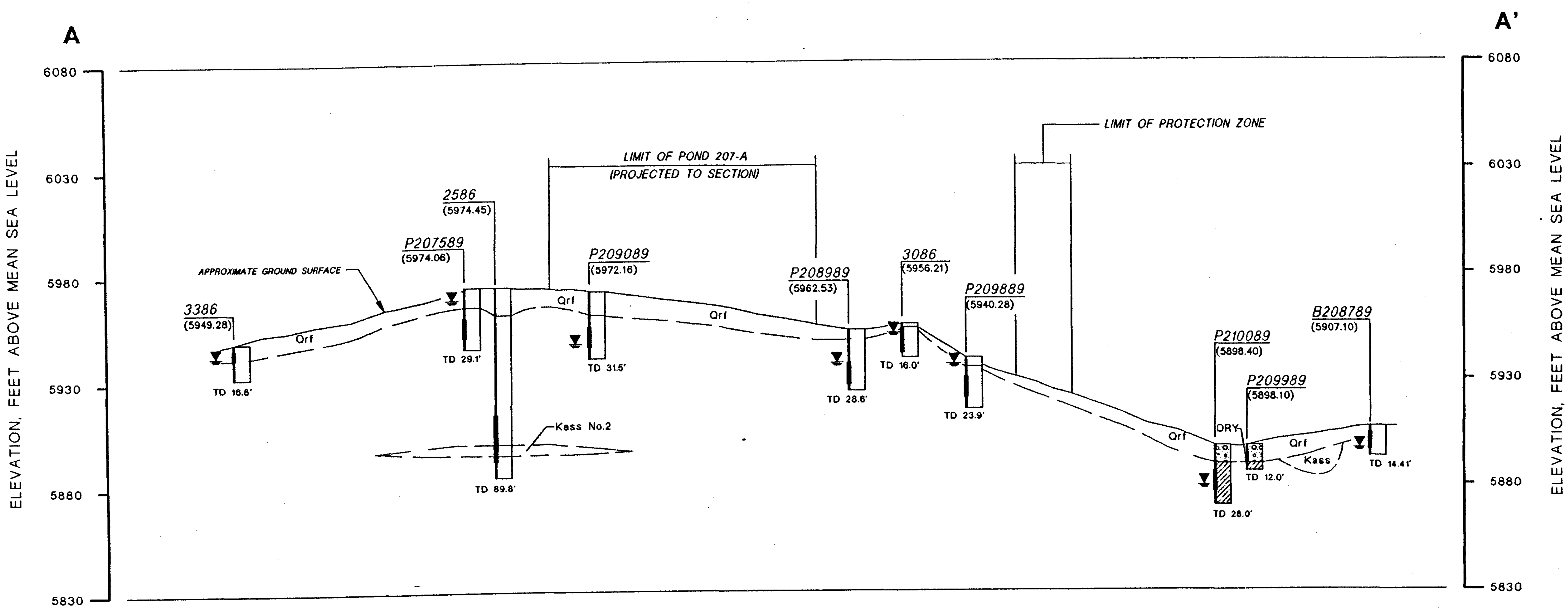

(LOOKING SOUTHWEST)

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

HORIZONTAL SCALE
0 200 400 FEET

VERTICAL SCALE
0 50 100 FEET

LEGEND

3386 (5949.28) — WELL IDENTIFICATION — GROUND SUFRACE ELEVATION

— SCREENED INTERVAL

— WATER LEVEL - 7/90 1990 ANNUAL RCRA GROUNDWATER MONITORING REPORT EG&G RFEDs (DATA BASE)

TD 31.5' — TOTAL DEPTH DRILLED

QUATERNARY

GRAVEL — Qrf — ROCKY FLATS ALLUVIUM

CRETACEOUS

SANDSTONE — Kass — ARAPAHOE SANDSTONE

SILTY CLAYSTONE — Kasc — ARAPAHOE SILTY CLAYSTONE

CLAYSTONE — Kacs — ARAPAHOE CLAYSTONE

SOURCE:
FIGURE 2-10 FROM OU4 PHASE 1 RFI/RI WORK PLAN

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FIGURE A-9
GEOLOGIC CROSS SECTION
A - A'
SOLAR PONDS - OU4

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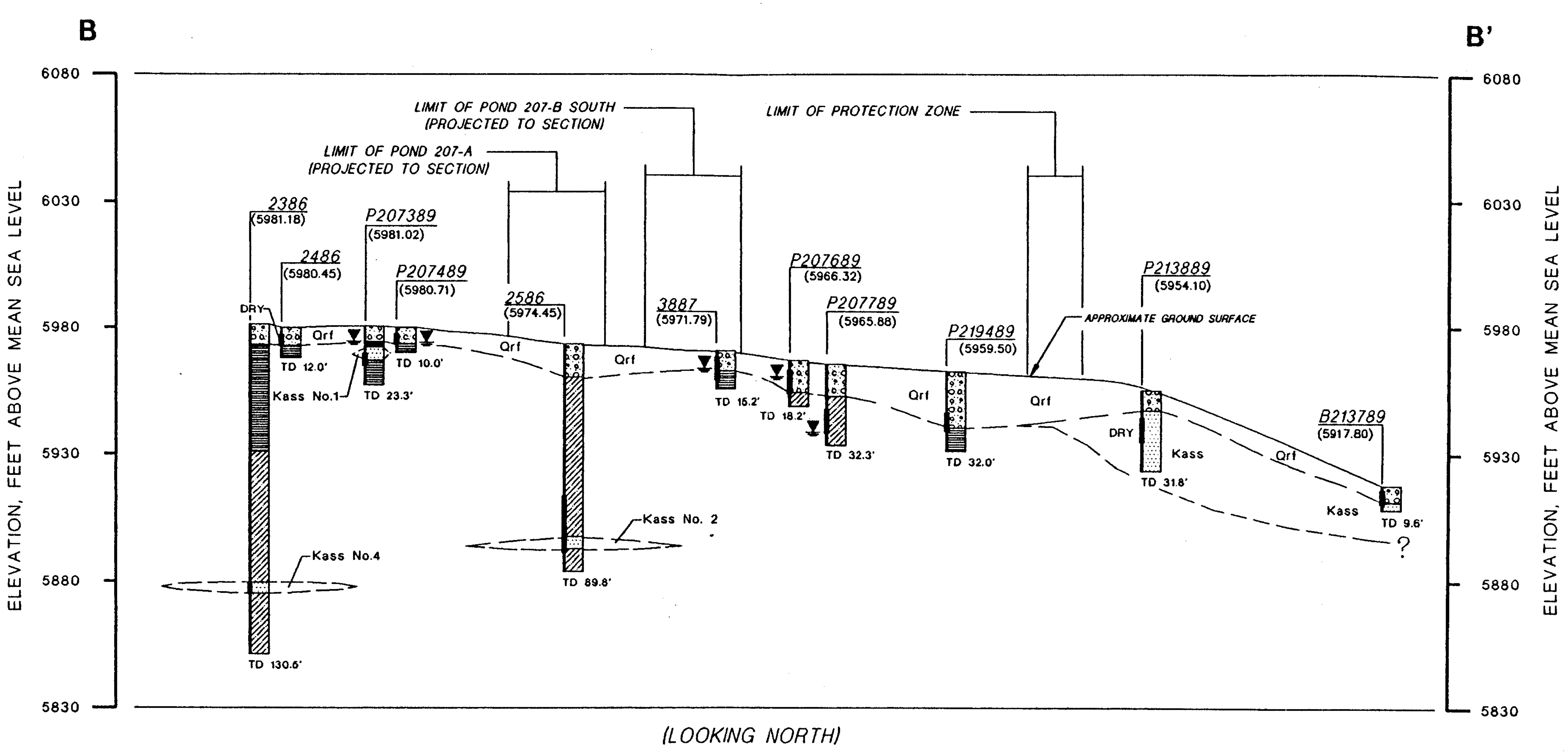

(LOOKING NORTH)

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

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HORIZONTAL SCALE

0 300 600 FEET

VERTICAL SCALE

0 50 100 FEET

LEGEND

3386 — WELL IDENTIFICATION
(5949.28) — GROUND SUFRACE ELEVATION

— SCREENED INTERVAL

— WATER LEVEL - 7/90
1990 ANNUAL RCRA GROUNDWATER MONITORING REPORT
EG&G RFEDs (DATA BASE)

TD 31.5' — TOTAL DEPTH DRILLED

QUATERNARY

GRAVEL	Qrf	ROCKY FLATS ALLUVIUM

CRETACEOUS

SANDSTONE	Kass	ARAPAHOE SANDSTONE
SILTY CLAYSTONE	Kasc	ARAPAHOE SILTY CLAYSTONE
CLAYSTONE	Kacs	ARAPAHOE CLAYSTONE

SOURCE:
FIGURE 2-11 FROM OU4 PHASE 1 RFI/RI WORK PLAN

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FIGURE A-10
GEOLOGIC CROSS SECTION
B - B'
SOLAR PONDS - OU4

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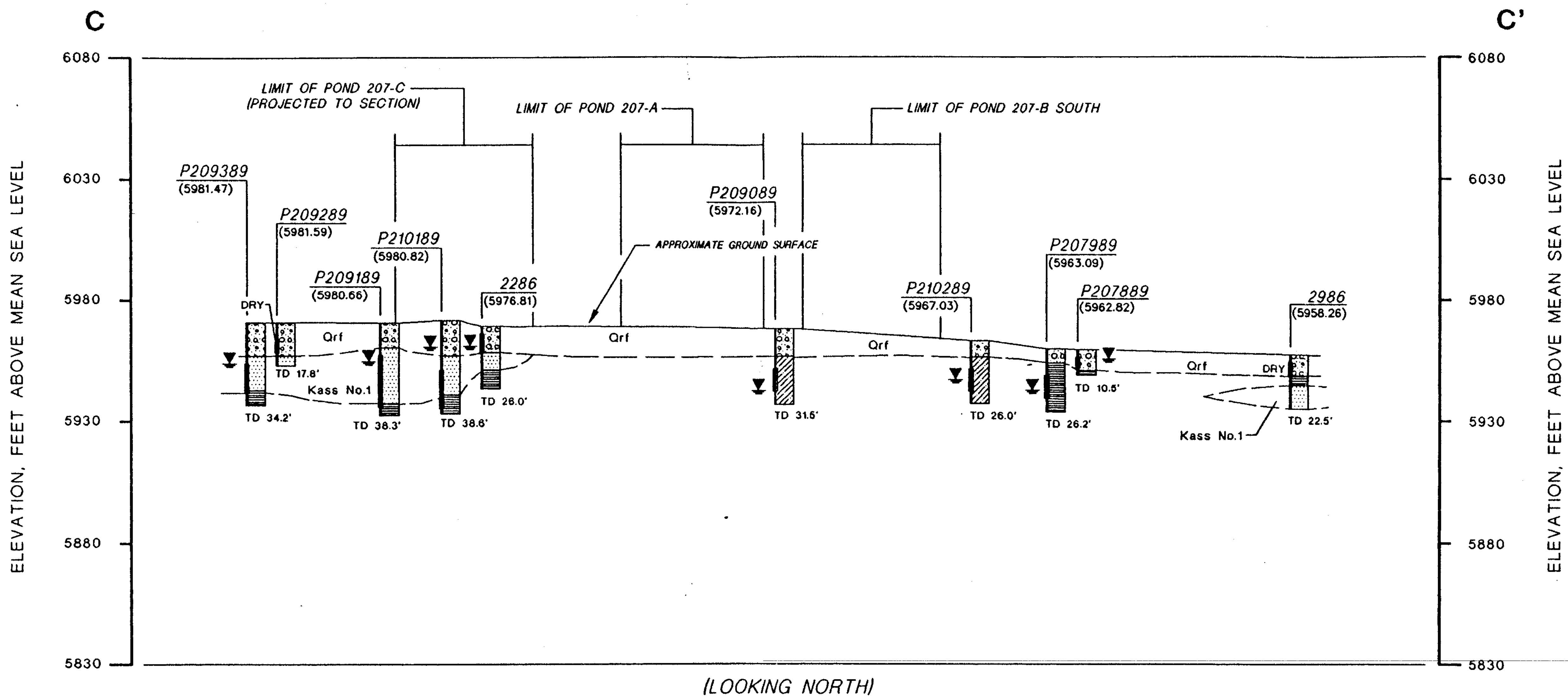

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HORIZONTAL SCALE

0 200 400 FEET

VERTICAL SCALE

0 50 100 FEET

LEGEND

3386 — WELL IDENTIFICATION
(5949.28) — GROUND SUFRACE ELEVATION

— SCREENED INTERVAL

— WATER LEVEL - 7/90 1990 ANNUAL RCRA GROUNDWATER MONITORING REPORT EG&G RFEDs (DATA BASE)

TD 31.5' — TOTAL DEPTH DRILLED

QUATERNARY

GRAVEL	Qrf	ROCKY FLATS ALLUVIUM

CRETACEOUS

SANDSTONE	Kass	ARAPAHOE SANDSTONE
SILTY CLAYSTONE	Kasc	ARAPAHOE SILTY CLAYSTONE
CLAYSTONE	Kacs	ARAPAHOE CLAYSTONE

SOURCE:
FIGURE 2-12 FROM OU4 PHASE 1 RFI/RI WORK PLAN

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FIGURE A-11
GEOLOGIC CROSS SECTION
C - C'
SOLAR PONDS - OU4

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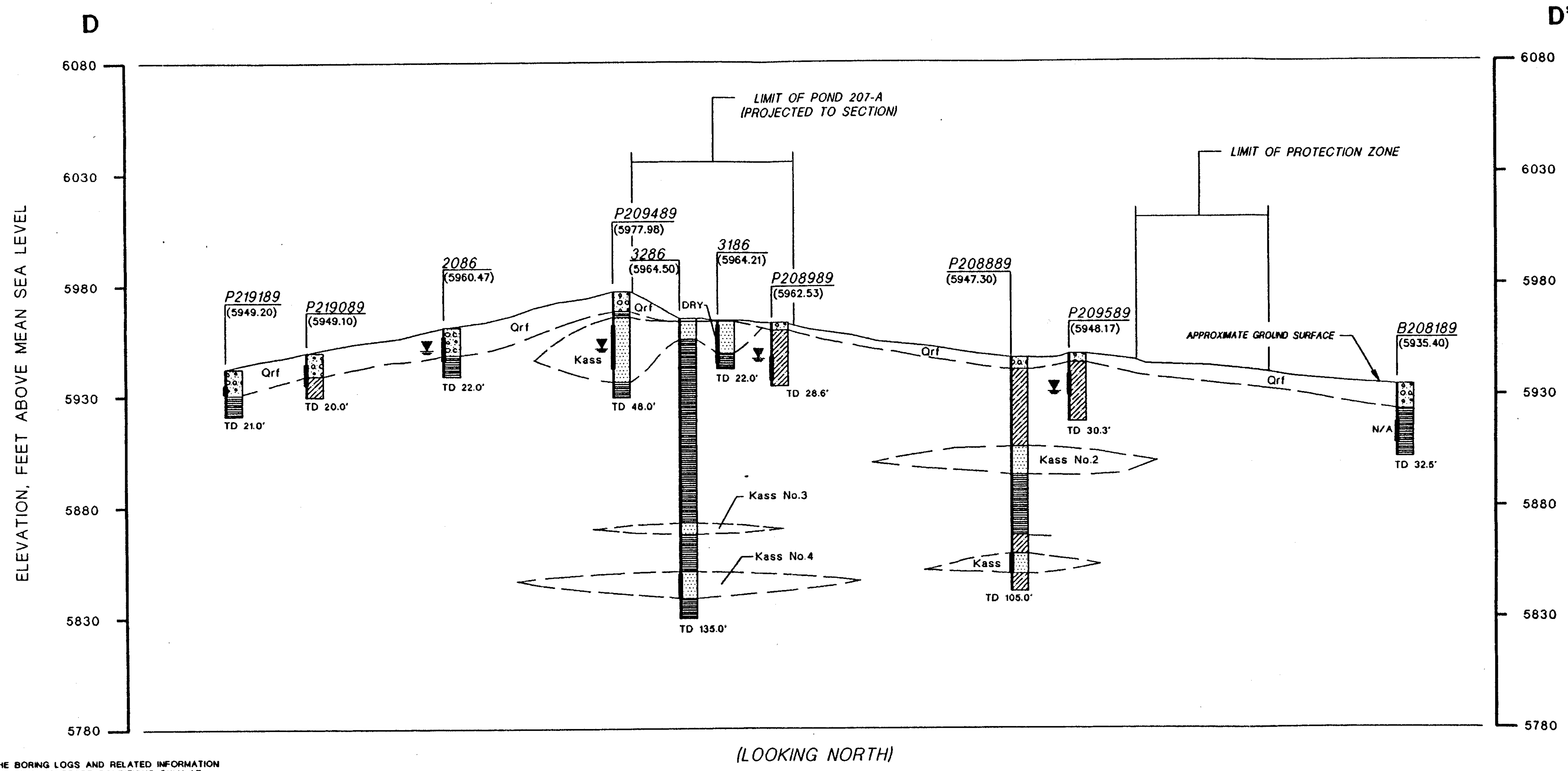

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HORIZONTAL SCALE

0 200 400 FEET

VERTICAL SCALE

0 50 100 FEET

LEGEND

3386 (5949.28) — WELL IDENTIFICATION — GROUND SUFRACE ELEVATION

— SCREENED INTERVAL

— WATER LEVEL - 7/90 1990 ANNUAL RCRA GROUNDWATER MONITORING REPORT EG&G RFEDs (DATA BASE)

TD 31.5' — TOTAL DEPTH DRILLED

	QUATERNARY	
GRAVEL	Qrf	ROCKY FLATS ALLUVIUM
	CRETACEOUS	
SANDSTONE	Kass	ARAPAHOE SANDSTONE
SILTY CLAYSTONE	Kasc	ARAPAHOE SILTY CLAYSTONE
CLAYSTONE	Kacs	ARAPAHOE CLAYSTONE

SOURCE:
FIGURE 2-13 FROM OU4 PHASE 1 RFI/RI WORK PLAN

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FIGURE A-12
GEOLOGIC CROSS SECTION
D - D'
SOLAR PONDS - OU4

REVISION NO. 0 | FILE NAME 40104.50 VZTN | DATE 12/10/92 | DRAWN BY JAA | APPROVED BY | CHECKED BY